A

TREATISE

OF

MECHANICS,

THEORETICAL, PRACTICAL,

AND

DESCRIPTIVE.

BY OLINTHUS GREGORY, LL.D.

Corresponding Associate of the Academy of Dijon; Honorary Member of the Literary and Philosophical Society of New York; of the New York Historical Society; of the Literary and Philosophical, and the Antiquarian Societies of Newcastle-upon-Tyne; of the Cambridge Philosophical Society; of the Institution of Civil Engineers, &c. &c. Secretary to the Astronomical Society of London, and Professor of Mathematics in the Royal Military Academy.

THE FOURTH EDITION,

CORRECTED AND IMPROVED.

VOL. II.

CONTAINING

REMARKS ON THE NATURE, CONSTRUCTION, AND SIMPLIFICATION OF MACHINERY, ON FRICTION, RIGIDITY OF CORDS, FIRST MOVERS, &c.

AND

DESCRIPTIONS OF MANY CURIOUS AND USEFUL MACHINES.

——. Talem intelligo Philosophiam naturalem, quæ non abeat in fumos speculationum subtilium, aut sublimium; sed quæ efficaciter operetur ad sublevandi vitæ humanæ incommoda. *Bacon. De Aug. Sci.*

LONDON:

PRINTED FOR GEO. B. WHITTAKER; LONGMAN, HURST, REES, ORME, AND CO.; C. AND J. RIVINGTON; BALDWIN, CRADOCK, AND JOY; J. RICHARDSON; HARDING AND CO.; J. TAYLOR; R. SCHOLEY; SAUNDERS AND HODGSON; J. DUNCAN; BAYNES AND SON; SHERWOOD AND CO.; HAMILTON AND CO.; J. BOOKER; SIMPKIN AND MARSHALL; W. MASON; J. WICKSTEED; AND WIGHTMAN AND CRAMP.

1826.

LONDON:
PRINTED BY THOMAS DAVISON, WHITEFRIARS.

CONTENTS

OF

VOLUME II.

PRACTICAL MECHANICS.

DESCRIPTIONS OF MACHINES.

CORRECTION.

In article 29. B, page 34, when treating of the great augmentation of the friction of cords coiled round cylinders, it is affirmed that "the practical result differs only *in a small degree* from this result of an assumed theory." But the assertion must be greatly modified. Mr. B. *Bevan*, an ingenious and scientific engineer, has subjected the point to the test of experiment, and his results have been published in the *Mechanic's Magazine*, as below:—

1st. He took a cord of 392 feet to the pound, to which he attached a weight of one pound, and applied it to a cylinder of dry ash-wood, turned in a lathe 1·75 inches' diameter, and ascertained the force of traction necessary to raise this single pound weight, and found when the cord was in contact with half the circumference of the cylinder, the force required was - - - 2 lbs.

at one and a half turns	13
at two and a half	31
at three and a half	66

2nd. He then tried, upon the same ash cylinder, another line, very flexible, of 92 feet to the pound, loaded with one pound, as before, and the force of traction observed was,

At half a turn - - -	$2\frac{1}{2}$ lbs.
one and a half turns - -	10
two and a half - - -	30
three and a half - - -	83

3d. He next took the line of 92 feet to the pound, loaded with one pound, upon a cylinder of cast iron, rough from the foundry, of 4·5 inches diameter, and found the traction to be,

At half a turn - - -	6 lbs.
one and a half - - -	98

4th. Applied the same line to a cylinder of cast iron, turned but not polished, of one inch diameter, and found the traction to be,

At half a turn - - -	$2\frac{1}{4}$ lbs.
one and a half - - -	8
two and a half - - -	23
three and a half - - -	56

5th. Upon the same cylinder he tried a new *stiff* cord of 114 feet to the pound, and fonnd the traction,

At half a turn - - -	2 lbs.
one and a half - - -	6
two and a half - - -	20
three and a half - - -	39

6th. His next experiment was upon a glass cylinder, of ·95 inch diameter, with the above-named *flexible* line of 92 feet to the pound, and found the traction,

At half a turn - - -	$1\frac{1}{2}$ lbs.
one and a half - - -	3
two and a half - - -	$5\frac{1}{2}$
three and a half - - -	13

7th. Upon a glass cylinder of ·95 inch diameter (as in experiment 6th), he used the *stiff* cord employed in experiment 5th, and found the traction,

At half a turn - - -	$1\frac{1}{2}$ lbs.
one and a half - - -	$2\frac{1}{2}$
two and a half - - -	4
three and a half - - -	$6\frac{1}{2}$
four and a half - - -	11

8th. He then applied the line used in experiment 2nd to a glass cylinder of four inches diameter, loaded with the same constant weight of one pound, and found the traction,

At half a turn - - -	$1\frac{3}{4}$ lbs.
one and a half - - -	4
two and a half - - -	9

I have tried a few experiments of a similar kind, in my own lectures on friction, and find them to accord very nearly with those of Mr. Bevan. The following is one of the results. I took a piece of patent white rope, $3\frac{1}{2}$ feet long, circumference 1·1 inch, and coiled it over a piece of deal rod 1·3 inch diameter; at one end a weight of 1 pound was hung, at the other end the weights required just to produce motion were,

At half a turn - - -	$2\frac{3}{4}$ lbs.
one and a half - - -	14
two and a half - - -	$29\frac{1}{2}$
three and a half - - -	84

MECHANICS.

REMARKS ON MACHINERY IN GENERAL.

1. MECHANICS, according to the original import of the word, treats of the energy of Machines: and these machines are nothing more than *organa*, or tools, interposed between the workman, or natural agent, and the task to be accomplished, in order to render that work capable of being performed, which under the limits and circumstances proposed would have been difficult, if not impossible, without the intervention of some of these contrivances.

Machines are interposed, as was remarked (art. 379. vol. I.), chiefly for three reasons. 1. To accommodate the direction of the moving force, to that of the resistance which is to be overcome. 2. To render a power which has a fixed and certain velocity efficacious in performing work with a different velocity. 3. To enable a natural power, having a certain determinate intensity, to balance or to overcome another power or obstacle, whose intensity or resistance is greater. Each of these purposes may be accomplished in different ways: *i. e.* either by machines which have a motion round some fixed and supported point, as the lever, the pulley, and the wheel and axle; or by those which, instead of being supported by a fixed *point*, about which they move, furnish to the resistance, or body to be moved, a solid path, along which it is impelled, as the inclined plane, the wedge, and the screw. Compound machines are peculiar combinations of these six, of which we have treated individually in the first book of our first volume: some remarks likewise upon their combination have been given in Book I. Chap. IV. art. 161. and Book II. Chap. VI. And we have treated of the strength of the materials of which machines may be composed, in Book I. Chap. V. Such farther observations as appear necessary to complete a theoretical and practical knowledge of Machinery in general, previous to our alphabetical description of particular machines, will now be presented to the student.

2. Simplicity in the construction of machines cannot be too warmly recommended to the young engineer: for multiplicity of parts and of motions increases the expense of erection, augments the friction, and multiplies the danger of failure by the bending or by the inaccurate adjustment of the parts. In consequence of the effects of friction (of which we shall speak more fully, art. 24, &c.), it is well known to all engaged in the practice of mechanics, that by no combination of wheels, or levers, or other powers, can one weight be made to move another with a greater or even an equal momentum: and by the multiplication of wheels, levers, &c. the effect of the machine, instead of being increased, is diminished in proportion to the augmented friction of the moving parts. Hence it follows that, in practice, effect is lost by mechanical combination, but gained by simplification; and that the most perfect machine is that which operates by the fewest moving parts. In order to contrive a simple machine to be theoretically equivalent in power to a complex one, the following rule may be observed: Construct the various parts of the simpler machine so that the velocity of the impelled point (art. 365.) shall be to that of the working point, in the same ratio as they are in the compound machine; then will the effects of these two machines be the same, so far as depends upon pure theory: but in practice the simpler will be the more efficacious, in consequence of the diminution of friction.

3. For an example, suppose the compound machine, fig. 1. pl. II. were to be proposed, in order that a more simple one might be constructed to perform the same work. Let CA, the lever to which the power is applied, be 10 feet, DE 5 feet in diameter, EF $=$ 2 feet, HI $=$ 3 feet, GH $=$ 5 feet, and KL $=$ 1 foot, the latter being the cylinder on which the rope raising the weight W folds. Now the diameter of the circle described by the power at A is 20 feet: and to find the diameter of the circle whose circumference is equal to the space passed over by W in one revolution of the lever CA, reduce the following fraction, viz. $\frac{\text{DE}}{2\text{AC}} \times \frac{\text{GH}}{\text{EF}} \times \frac{\text{KL}}{\text{HI}} = \frac{5}{20} \times \frac{5}{2} \times \frac{1}{3} = \frac{5}{24}$ of 2AC; consequently the velocity of the weight is $\frac{5}{24}$ of that of the power. And hence, if upon the vertical axis CM (fig. 2. pl. II.) a wheel be fixed, the diameter kl of which is equal to $4\frac{1}{6}$ feet (that is, $\frac{5}{24}$ of 2AC), the weight W will be raised the same height by the simple as by the compound machine, at every revolution of the power A. So that, the simple machine ACMkl, will be at least equal in effect to the compound one ACMDEFGHIKL, and the wheels DE, EF, GH, HI, and KL, are extraneous, and probably prejudicial.

4. For another example take the following. In the common wheel and axle, the advantage gained is in the ratio of the radius of the winch to that of the barrel: so that when it is proposed to increase that advantage, either the handle must be lengthened, or the diameter of the axle diminished; neither of which, however, is practicable beyond certain limits, because the handle might be too long for convenient management, or the axle too slender to support the load: in such cases it is usual to annex another wheel or pinion, or a tackle of pulleys. But the following construction is greatly preferable. In fig. 7. pl. I. the part A of the barrel is larger than the part B, and the rope which passes under the pulley C and sustains the weight D is wound upon each in contrary directions. Whenever, therefore, the handle EF is turned, so as to gather the rope upon the larger cylinder, it will be given off by the smaller: and for every turn of the larger, or its correspondent portion of rope wound up, there will be given off a portion of rope answering to the circumference of the smaller. Consequently, the quantity of unwound rope will be less after such a turn, by a portion equal to the difference between the circumferences of the two cylinders; and the weight D will be raised through half that space. Whence, since the radii of circles are as their circumferences, we may use this analogy:

As the radius of the winch,
To half the difference of the radii of the cylinders;
So is the weight,
To the power balancing it.

In fig. 8. is exhibited a simple capstan in which the same contrivance is adopted. Here, if the upper barrel A were 17 inches diameter, and the lower B 16 inches, the pulley C being also 16 inches diameter; this simple capstan would be equivalent to an ordinary capstan of the same length of bar EF, and diameter of barrel B, combined with a 16-fold tackle of pulleys; and at the same time free from the great loss by friction and bending of ropes, which would absorb at least a third of the power of a 16-fold tackle.

One peculiar advantage of this engine is, that the half difference of the radii of A and B may be diminished *ad libitum*, without weakening the cylinder, increasing the friction, or requiring any rapid curvature of the rope. This windlass has likewise the peculiar property of holding the weight at any part of its rise or fall without needing a rachet wheel and catch. Its only practical disadvantage is, that a great quantity of rope must be used to produce a moderate change in the position of the weight; but the quantity of rope will be much less than what is requisite for an equivalent tackle of pulleys. This ingenious

contrivance is generally ascribed to the celebrated *George Eckhardt;* and he probably invented it without knowing that it had been used elsewhere: but we have seen a figure, from which our figure 8. is merely a copy, in some Chinese drawings of nearly a century old.

5. The methods of communicating motion from one thing to another, or from one point to another, are almost infinitely diversified: so that it will not be expected that they should all be described here. It is manifest that the communication of motion will in different circumstances be better effected by means of one simple machine (or, as they are usually called, mechanical power), than by another; and much of the skill of the engineer consists in choosing the instrument most proper for the purpose proposed: and the same will be the case with regard to more complex machines. In some instances a simple lever, or a simple unbent cord, will answer better than any combination: in others it may be highly advantageous to use a combination of levers acting upon each other, by means of so many fulcra; and by these the *direction* may be changed at pleasure: in others, as when motion is communicated to a series of wheels and axles in succession, it may be effected by a rope running in grooves round one wheel and the succeeding axle; or by what was described in vol. I. art. 246. under the name of tooth and pinion work: in others again, by a barrel and winch with an endless screw. And many other contrivances will readily suggest themselves to an ingenious artist. See article seventh, under *Surface-planing machinery,* in this volume.

6. But such simple methods cannot always be adopted. Thus when it is required *by means of a rotatory motion to produce a reciprocating one,* as the alternate motion of the pistons of pumps, for example; one of the following contrivances may be used. To a vertical shaft as AP (fig. 6. pl. II.) fix a large horizontal wheel MOIL, the lower part of which is indented in waves MSO, OQI, &c. of which the constituent arches are either circular or parabolic. On a convenient point D of an upright post as a centre of motion, let a lever EDC move; one end of it carrying the moveable vertical wheel CR, in size properly adjusted to the waves of the horizontal wheel; the other EF being a circular arc to which is applied the chain EG of the pump. Then whilst the great wheel is turned by the lever NA from O towards I, the wave Q presses down the wheel QR, and raises the end E of the lever, and thus draws up the water in the pump G. But when the deepest part O of the wave is past the highest part of the wheel CR, the wheel rises up into the hollow S, and so the chain EG descends till the next wave raises it again. Thus the passage of every wave by the wheel

CR causes a stroke of the pump. If the number of waves be *odd*, and another pump wheel and lever be placed diametrically opposite on the other side of the great wheel; then these two levers acting by turns, will keep the motion tolerably uniform, and the power at N will have nearly a uniform action. The wheel CR is introduced for the sake of softening the friction: but it must be carefully adjusted to the magnitude of the waves, or else the motion will be hobbling and irregular. On this account the following method of obtaining a reciprocating motion is more usual.

Instead of making the axis AB (fig. 3. pl. II.) in one continued straight line, let it be bent at right angles in the points *d*, *e*, *f*, *g*, *h*, &c. so that the portions *ef*, *gh*, shall be parallel to AB, and in the course of a rotation of the lantern or trundle EF, they will describe cylindrical surfaces: if, then, pistons and their handles I*b*, I*b*, be hung upon the cranks I, I, as the rotatory motion of the trundle EF (when worked by another wheel) proceeds, the pistons are alternately forced up and down in the pumps; and thus make one complete stroke of each pump for every turn of the lantern. It will be advisable to place pulleys or rollers at *a*, *b*, *a*, *b*, for the handles or chains to work against, when the obliquity of the motion of the cranks I, I, carries them out of the vertical position.

Other methods of obtaining reciprocating by means of circular motions may be seen under the articles *Air-pump* and *Saw-mill*. See also pl. XXXVIII. and XXXIX.

7. *To produce a rotatory motion by means of a reciprocating one.* Suppose it is required to give to the wheel *s*VTO (fig. 4. pl. II.) a rotatory motion about the centre C. In the plane of the wheel, attach to a fixed point F as a centre of motion a lever FQ, which may move freely up and down: let a pin be fixed in the wheel as at R; and let an inflexible bar QR hang upon the pin at R at one end, while the other end is attached to the lever FQ by a stirrup; the motion being quite easy at both ends. Then, while the point Q is raised upwards, the bar pulls upwards the pin R, and so continues to do until the points Q, R, and C, fall in a right line; at that time the effort of the bar to turn the wheel is nothing; but the wheel by its anterior rotation has acquired a quantity of motion which will carry it on in the same direction, till by the downward motion of the extremity Q of the lever, the bar begins to *push* forward the pin to which it is attached: thus the motion is continued till the points Q, C, and R, are again in a right line, R being now the farthest from Q: in this position the bar has no tendency to move the wheel along; but here the effort of momentum continues the motion, as before, till the bar begins to draw the point

R upwards. And thus a reciprocating motion of the lever FR gives a complete rotation to the wheel; and the velocity of the circumference of the wheel may be made as rapid as we please, by making the distance CR so much the smaller in comparison of CV. If the lever FQ be below the wheel, the general effect will be the same, but the particular circumstances of the motion will succeed each other in a contrary order. In practice it is common to substitute for the pin at R the handle of a bent winch, as represented by the dotted lines in the figure. It is not absolutely necessary that the lever and wheel should be in the same plane; but deviations from it are not often to be recommended, except in small machinery, such as a common spinning wheel worked by the feet, &c. When it is not required to have a complete rotation of the wheel, for every ascent and descent of the lever FQ, we may change the relation of the two motions in any proportion, by the intervention of tooth and pinion work.

8. *To describe a rectilinear reciprocating motion, by means of an angular or circular reciprocating motion.* Let it be proposed, for example, to move the end F of the beam FH to and fro in the line EC. Fix a beam AB (fig. 9. pl. I.) perpendicularly to the given line EC, and cut in that beam a groove CD equal in length to the beam FH: let the end H of the beam FH be confined by a pin to run along the groove CD; and let two other pins be fixed, one at G the middle point of the beam FH, the other at C the lower point where the reciprocating motion of the point F terminates: take an iron bar CG equal in length to half FH, and let it move upon the pins C and G as joints. Then while the end G of the bar or guide CG moves through the quadrantal arc L*g* GK; the point H of the beam will slide along the groove from D to C, and the point F along the line CE from C to E: and when the guide returns from K by G to L, the end F of the beam will return along the line EC. For, when CG = GF = GH, supposing a line drawn from C to F, the angle FGC = GCH + GHC = 2GCH; and CGH = GCF + GFC = 2GCF. Hence we have 2 GCF + 2 GCH = FGC + HGC = 2 right angles, and consequently GCF + GCH = HCF = 1 right angle: that is, the point F falls in a right line drawn through C at right angles to CD. And when FH is in any other position, as *fh*, the same may be shown.

9. *To communicate motion in any direction by wheels, and to construct the wheels for that purpose.* This may be done by placing the wheels so that their shafts or axles shall be inclined in given angles, as represented in figs. 1. and 7. pl. III. And in this case the wheels are seldom portions of cylinders, but most commonly portions of cones. When the wheels do not

make an angle of 90°, the adjustment of the shape and magnitude of the conic frustums which constitute the wheels, is known among millwrights by the name of *bevel-geer* work; a concise account of which is here added. If two cones A and B (fig. 2. pl. III.), whose surfaces always touch in a right line, as *ae*, revolve on their axes *ab*, *ac*, rolling the one upon the other; and if the bases and altitudes of these cones be equal, they will perform complete revolutions in one and the same time. For since the bases and altitudes are equal, circles on either cone parallel to the base, and at equal distances from the vertex, as the distances *a*2, *a*2, for instance, will be equal: and therefore, while the surfaces of the cones roll one upon another, every point in the circumference of one of these circles will be brought successively into contact with a corresponding point on the circumference of the other, and they will both have revolved in an equal time. The same will hold of the corresponding circles at any other equal distances from the vertex, *a*1, *a*3, *a*4, &c. and consequently the two cones will perform their rotations in equal times.

Again, if the cone *ade* (fig. 3. pl. III.) have the diameter of its base double that of the cone *adf*, while their slant heights are the same; and if these two cones turn on their axes *ac*, *ab*, their surfaces during the rotation always touching one another in a right line; then, since the circumference of the base *de* is double that of the base *df*, and the circumference of every circular section parallel to the former base, double that of every corresponding section parallel to the latter base, it follows that when the cone *afd* has performed one rotation, the cone *ade* will have made but half a rotation. The times of rotation being in the ratio of their bases.

In like manner, if the cone *aed*, (fig. 4. pl. III.) have the diameter of its base, to the diameter of the base of *adf*, as *m* to *n*, the slant heights being the same; and if these cones turn upon their axes *ac*, *ab*, their surfaces being always in contact in some right line as *ad*; then will the time of a complete rotation of the cone *aed*, be to the time of rotation of *adf*, as *m* to *n*; and consequently the number of rotations of the former cone to the number of rotations of the latter in any given time, as *n* to *m*. And if these cones were fluted, the flutes diverging continually from the apex *a* to the base, they would become conical wheels, and constitute *bevel-geer*.

10. Thus, if B*b* and B*d* (fig. 5. pl. III.) be the bases of two cones turning on their axes, having teeth cut in them diverging from the common vertex A to those bases, such teeth will work freely into one another from one end to the other: but, as such teeth would be very difficult of adjustment towards the point A,

and because in practice the two axes could not both be properly fixed to one and the same point; it is necessary to cut off a portion, as AFE, from the upper part of both cones, and apply the axles to the lower parts in the same manner as in common wheels. The great advantages of these conical wheels are, that their teeth may be made of any breadth, according to the stress they are to sustain; and that the friction will be small in comparison of that occasioned by most other methods of communicating motion in oblique directions.

11. Now, *to determine the dimensions of two conical wheels to communicate motion in any oblique angle, the following graphic method may be used.* Suppose ab (fig. 6. pl. III.) to represent the shaft or axle of one wheel, and de the axle of another wheel, the angle x in which they intersect each other being equal to the angle in which the motion is proposed to be communicated: let it be required for the shaft de to revolve m times while the shaft ab revolves n times; and let the line ii be drawn parallel to de at a distance equal to the radius of the base of the wheel whose axle is de. Then draw a line kk parallel to ab, and at a distance yg from it, which shall be to the distance yh as m to n: through x the point of intersection of the lines first proposed, and y the intersection of the two lines ii, kk, respectively parallel to the two former, draw the line xyw, which will be the pitch line of the two conical wheels, or the line in which the teeth of those wheels act upon one another; and gy, hy will represent the exterior radii of the wheels, which will work one against the other after the manner shown in fig. 7, where the corresponding parts are marked by the same letters. A third shaft and wheel may easily be applied to communicate motion in a different direction from either of the former: as the shaft and wheel $rstv$ in fig. 7.

It is manifest from what is done above, that this is nothing more than to divide an angle bxh into two parts whose sines shall have a given ratio of m to n: a well-known problem which solved algebraically gives the theorem, $2 \sin \frac{1}{2} gxy = 2 \sin \frac{1}{2} gxh \cdot \frac{m}{m+n}$. (*Simpson's Select Exercises*, p. 138.) So that all which is required here may be easily calculated, when necessary, by the common rules of plane trigonometry.

12. *Universal joints* (invented by Dr. Hooke) are sometimes used to communicate motion obliquely, instead of conical wheels. Fig. 8. pl. III. represents a *single* universal joint which may be employed where the angle does not exceed 40 degrees, and when the shafts are to move with equal velocity. The shafts A and B, being both connected with a cross, will move on

the rounds at the point CE and DF, and thus if the shaft A is turned round, the shaft B will likewise turn with a similar motion in its respective position.

The *double* universal joint (fig. 9. pl. III.) conveys motion in different directions when the angle is between 50 and 90 degrees. It is at liberty to move on the rounds at the points G, H, I, K, connected with the shaft B; also on the points L, M, N, T, connected with the shaft A: thus the two shafts are so connected that one cannot turn without causing the other to turn likewise. These joints may be constructed by a cross of iron, or with four pins fastened at right angles upon the circumference of a hoop or of a solid ball: they are of great use in cotton mills, where the tumbling shafts are continued to a great distance from the moving power: for by applying a universal joint, the shafts may be cut into convenient lengths, and so be enabled to overcome a greater resistance.

13. *When the number of teeth in each of two wheels is given, and the diameter of one of them, the diameter of the other should be so found that one wheel may drive the other without shaking:* and for this purpose there will be a different proportion of diameters or of radii, according to the number of teeth which are to be in contact. Let ADE, BDF (fig. 10. pl. III.) represent portions of the wheels, C the point where the teeth ought first to come into contact: draw CD perpendicular to AB the right line joining the centres of the wheels; and if this be reckoned the radius, CB will be the secant of the angle DCB, and AC the secant of the angle DCA. Consequently, CB : CA : : secant DCB : secant DCA : : cosec. DBC : cosec. DAC. But, the number of teeth in each wheel being given, the angles DBC, DAC, vary as half the number of teeth in contact. Therefore, divide the arch of the semicircle, or 180 degrees, by half the number of teeth in each wheel, and proportion the radii of the wheel to the cosecants of the quotients, or of double, or of treble the quotients, according to the depth of the wheels running, viz. according as they are to have two, four, or six teeth, in contact; so shall the motion be regular and free from shaking.

In art. 147. of the first volume, we described the best forms for the teeth of wheels: in many cases, however, a small deviation from these perfect forms is not of great importance. But in cases where the utmost accuracy is required, as in the pallets of clocks and watches, the form of the teeth must be carefully attended to. See the article TEETH in this volume.

14. *To regulate any motion and make it uniform,* one of the most obvious methods is that by means of a pendulum and scapement. Thus, (fig. 5. pl. II.) as the pendulum AB vibrates, it causes EFG to vibrate also, about the axis FG: whilst the pen-

dulum vibrates towards D, a tooth of the wheel KL goes off the pallet I, and another catches the pallet H: and when the pendulum returns towards C, it draws the pallet H off the tooth, and another catches the pallet I; and so on alternately. So that, at every vibration of the pendulum, a tooth goes off one or other of the pallets: and, as the vibrations of the pendulum are isochronous, the teeth move from the pallets uniformly, the whole rotation of the wheel KL is made regularly, and by reason of the connexion of the teeth and pinions the descent of W is uniform, which would otherwise have been accelerated. See SCAPEMENTS.

15. Professor Robison has given some general observations on the construction of machines, and on the regulating of their motions, which appear highly worthy of the reader's attention, and are therefore extracted, as below.

When heavy stampers are to be raised, in order to drop on the matters to be pounded, the wipers by which they are lifted should be made of such a form, that the stamper may be raised by a uniform pressure, or with a motion almost perfectly uniform. If this is not attended to, and the wiper is only a pin sticking out from the axis, the stamper is forced into motion at once. This occasions violent jolts to the machine, and great strains on its moving parts and their points of support; whereas when they are gradually lifted, the inequality of desultory motion is never felt at the impelled point of the machine. We have seen pistons moved by means of a double rack on the piston-rod. A half wheel takes hold of one rack, and raises it to the required height. The moment the half wheel has quitted that side of the rack, it lays hold of the other side, and forces the piston down again. This is proposed as a great improvement; correcting the unequable motion of the piston moved in the common way by a crank. But it is far inferior to the crank motion. It occasions such abrupt changes of motion, that the machine is shaken by jolts. Indeed if the movement were accurately executed, the machine would be shaken to pieces, if the parts did not give way by bending and yielding. Accordingly, we have always observed that this motion soon failed, and was changed for one that was more smooth. A judicious engineer will avoid all such sudden changes of motion, especially in any ponderous part of a machine.

When several stampers, pistons, or other reciprocal movers, are to be raised and depressed, common sense teaches us to distribute their times of action in a uniform manner, so that the machine may always be equally loaded with work. When this is done, and the observations in the preceding paragraph attended to, the machine may be made to move almost as smoothly as if there were no reciprocations in it. Nothing shows the ingenuity

of the author more than the artful yet simple and effectual contrivances for obviating those difficulties that unavoidably arise from the very nature of the work that must be performed by the machine, and of the power employed.

16. There is also great room for ingenuity and good choice in the management of the moving power, when it is such as cannot immediately produce the kind of motion required for effecting the purpose. We mentioned the conversion of the continued rotation of an axis into the reciprocating motion of a piston, and the improvement which was thought to have been made on the common and obvious contrivance of a crank, by substituting a double rack on the piston-rod, and the inconvenience arising from the jolts occasioned by this change. We have seen a great forge, where the engineer, in order to avoid the same inconvenience arising from the abrupt motion given to the great sledge hammer of seven hundred weight, resisting with a five-fold momentum, formed the wipers into spirals, which communicated motion to the hammer almost without any jolt whatever; but the result was, that the hammer rose no higher than it had been raised in contact with the wiper, and then fell on the iron bloom with very little effect. The cause of its inefficiency was not guessed at; but it was removed, and wipers of the common form were put in place of the spirals. In this operation, the rapid motion of the hammer is absolutely necessary. It is not enough to *lift* it up; it must be *tossed* up, so as to fly higher than the wiper lifts it, and to strike with great force the strong oaken spring which is placed in its way. It compresses this spring, and is reflected by it with a considerable velocity, so as to hit the iron as if it had fallen from a great height. Had it been allowed to fly to that height, it would have fallen upon the iron with somewhat more force (because no oaken spring is perfectly elastic); but this would have required more than twice the time.

17. In employing a power which of necessity reciprocates, to drive machinery which requires a continuous motion (as in applying the steam engine to a cotton or a grist mill), there also occur great difficulties. The necessity of reciprocation in the first mover wastes much power; because the instrument which communicates such an enormous force must be extremely strong, and be well supported. The impelling power is wasted in imparting, and afterwards destroying, a vast quantity of motion in the working beam. The skilful engineer will attend to this, and do his utmost to procure the necessary strength of this first mover, without making it a vast load of inert matter. He will also remark, that all the strains on it, and on its supports, are changing their directions in every stroke. This re-

quires particular attention to the manner of supporting it. If we observe the steam engines which have been long erected, we see that they have uniformly shaken the building to pieces. This has been owing to the ignorance or inattention of the engineer in this particular. They are much more judiciously erected now, experience having taught the most ignorant that no building can withstand their desultory and opposite jolts, and that the great movements must be supported by a framework independent of the building of masonry which contains it *.

The engineer will also remark, that when a single-stroke steam engine is made to turn a mill, all the communications of motion change the direction of their pressure twice every stroke. During the working stroke of the beam, one side of the teeth of the intervening wheels is pressing the machinery forward; but during the returning stroke, the machinery, already in motion, is dragging the beam, and the wheels are acting with the other side of the teeth. This occasions a rattling at every change, and makes it proper to fashion both sides of the teeth with the same care.

It will frequently conduce to the good performance of an engine, to make the action of the resisting work unequable, accommodated to the inequalities of the impelling power. This will produce a more uniform motion in machines in which the momentum of inertia is inconsiderable. There are some beautiful specimens of this kind of adjustment in the mechanism of animal bodies.

18. It is very customary to add what is called a FLY to machines. This is a heavy disk or hoop, or other mass of matter *balanced on its axis*, and so connected with the machinery as to turn briskly round with it. This may be done with the view of rendering the motion of the whole more regular, notwithstanding unavoidable inequalities of the accelerating forces, or of the resistances occasioned by the work. It becomes a REGULATOR. Suppose the resistance extremely unequal, and the impelling power perfectly constant; as when a bucket wheel is employed to work *one* pump. When the piston has ended its working stroke, and while it is going down the barrel, the power of the wheel being scarcely opposed, it accelerates the whole machine, and the piston arrives at the bottom of the barrel with a con-

* The gudgeons of a water-wheel should never rest on the wall of the building. It shakes it; and if set up soon after the building has been erected, it prevents the mortar from taking firm bond; perhaps by shattering the calcareous crystals as they form. When the engineer is obliged to rest the gudgeons in this way, they should be supported by a block of oak laid a little hollow. This softens all tremors, like springs of a wheel carriage. This practice would be very serviceable in many other parts of the construction.

siderable velocity. But in the rising again, the wheel is opposed by the column of water now pressing on the piston. This immediately retards the wheel; and when the piston has reached the top of the barrel, all the acceleration is undone, and is to begin again. The motion of such a machine is very hobbling: but the superplus of accelerating force at the beginning of a returning stroke will not make such a change in the motion of the machine if we connect the fly with it. For the accelerating momentum is a determinate quantity. Therefore, if the radius of the fly be great, this momentum will be attained by communicating a small angular motion to the machine. The momentum of the fly is as the square of its radius; therefore it resists acceleration in this proportion; and although the overplus of power generates the same momentum of rotation in the whole machine as before, it makes but a small addition to its velocity. If the diameter of the fly be doubled, the augmentation of rotation will be reduced to one-fourth. Thus, by giving a rapid motion to a small quantity of matter, the great acceleration during the returning stroke of the piston is prevented. This acceleration continues, however, during the whole of the returning stroke, and at the end of it the machine has acquired its greatest velocity. Now the working stroke begins, and the overplus of power is at an end. The machine accelerates no more; but if the power is just in equilibrio with the resistance, it keeps the velocity which it has acquired, and is still more accelerated during the *next* returning stroke. But now, at the beginning of the subsequent working stroke, there is an overplus of resistance, and a retardation begins, and continues during the whole rise of the piston; but it is considerable in comparison of what it would have been without the fly; for the fly, retaining its acquired momentum, drags forward the rest of the machine, aiding the impelling power of the wheel. It does this by all the communications taking into each other in the opposite direction. The teeth of the intervening wheels are heard to drop from their former contact on one side, to a contact on the other. By considering this process with attention, we easily perceive that, in a few strokes, the overplus of power during the returning stroke comes to be so adjusted to the deficiency during the working stroke, that the accelerations and retardations exactly destroy each other, and every succeeding stroke is made with the same velocity, and an equal number of strokes is made in every succeeding minute. Thus the machine acquires a general uniformity with periodical inequalities. It is plain, that by sufficiently enlarging either the diameter or the weight of the fly, the irregularity of the motion may be rendered as small as we please. It is much better to enlarge the diameter,

This preserves the friction more moderate, and the pivot wears less. For these reasons, a fly is in general a considerable improvement in machinery, by equalising many exertions that are naturally very irregular. Thus, a man working at a common windlass exerts a very irregular pressure on the winch. In one of his positions in each turn he can exert a force of near 70 pounds without fatigue, but in another he cannot exert above 25; nor must he be loaded with much above this in general. But if a large fly be connected properly with the windlass, he will act with equal ease and speed against 30 pounds.

This regulating power of the fly is without bounds, and may be used to render uniform a motion produced by the most desultory and irregular power. It is thus that the most regular motion is given to mills that are driven by a single-stroke steam engine, where for two or even three seconds there is no force pressing the mill round. The communication is made through a massive fly of very great diameter, whirling with great rapidity. As soon as the impulse ceases, the fly, continuing its motion, urges round the whole machinery with almost unabated speed. At this instant all the teeth, and all the joints, between the fly and the first mover, are heard to catch in the opposite direction.

If any permanent change should happen in the impelling power, or in the resistance, the fly makes no obstacle to its producing its full effect on the machine; and it will be observed to accelerate or retard uniformly, till a new general speed is acquired exactly corresponding with this new power and resistance.

19. Many machines include in their construction movements which are equivalent to this intentional regulator. A flour mill, for example, cannot be better regulated than by its millstone; but in the Albion mills, a heavy fly was added with great propriety; for if the mills had been regulated by their millstones only, then at every change of stroke in the steam engine, the whole train of communications between the beam, which is the first mover, and the regulating millstone, which is the very last mover, would take in the opposite direction. Although each drop in the teeth and joints be but a trifle, the whole, added together, would make a considerable jolt. This is avoided by a regulator immediately adjoining to the beam. This continually presses the working machinery in one direction. So judiciously were the movements of that noble machine contrived, and so nicely were they executed, that not the least noise was heard, nor the slightest tremor felt in the building.

20. Mr. Valoué's beautiful pile engine employed at Westminster Bridge is another remarkable instance of the regulating power of a fly. When the ram is dropped, and its follower

disengaged immediately after it, the horses would instantly tumble down, because the load, against which they had been straining hard, is at once taken off; but the gin is connected with a very large fly, which checks any remarkable acceleration, allowing the horses to lean on it during the descent of the load; after which their draught recommences immediately. The spindles, cards, and bobbins, of a cotton mill, are also a sort of flies. Indeed all bulky machines of the rotative kind tend to preserve their motion with some degree of steadiness, and their great momentum of inertia is as useful in this respect as it is prejudicial to the acceleration or any reciprocation when wanted.

21. There is another kind of regulating fly, consisting of wings whirled briskly round till the resistance of the air prevents any great acceleration. This is a very bad one for a *working* machine, for it produces its effect by *really wasting* a part of the moving power. Frequently it employs a very great and unknown part of it, and robs the proprietor of much work. It should never be introduced into any machine employed in manufactures.

22. Some rare cases occur where a very different regulator is required: where a certain determined velocity is found necessary. In this case the machine is furnished, at its extreme mover, with a conical pendulum, consisting of two heavy balls hanging by rods, which move in very nice and steady joints at the top of a vertical axis. It is well known, that when this axis turns round, with an angular velocity suited to the length of those pendulums, the time of a revolution is determined. Thus, if the length of each pendulum be $39\frac{1}{5}$ inches, the axis will make a revolution in two seconds very nearly. If we attempt to force it more swiftly round, the balls will recede a little from the axis, but it employs as long time for a revolution as before; and we cannot make it turn swifter, unless the impelling power be increased beyond all probability: in which case the pendulum will fly out from the centre till the rods are horizontal, after which every increase of power will accelerate the machine very sensibly. Watt and Boulton first applied this contrivance with great ingenuity to their steam engines, when they are employed for driving machinery for manufactures which have a very changeable resistance, and where a certain speed cannot be much departed from without great inconvenience. They have connected this recess of the balls from the axis (which gives immediate indication of an increase of power or a diminution of resistance) with the cock which admits the steam to the working cylinder. The balls flying out cause the cock to close a little, and diminish the supply of steam. The impelling power diminishes the next

moment, and the balls again approach the axis, and the rotation goes on as before, although there may have occurred a very great excess or deficiency of power. See GOVERNOR.

23. A fly is sometimes employed for a very different purpose from that of a regulator of motion—it is employed as a *collector of power*. Suppose all resistance moved from the working point of a machine furnished with a very large or heavy fly immediately connected with the working point. When a small force is applied to the impelled point of this machine, motion will begin in the machine, and the fly begin to turn. Continue to press uniformly, and the machine will accelerate. This may be continued till the fly has acquired a very rapid motion. If at this moment a resisting body be applied to the working point, it will be acted on with very great force; for the fly has now accumulated in its circumference a very great momentum. If a body were exposed immediately to the action of this circumference, it would be violently struck. Much more will it be so, if the body be exposed to the action of the working point, which perhaps makes one turn while the fly makes a hundred. It will exert a hundred times more force there (very nearly) than at its own circumference. All the motion which has been accumulated on the fly during the whole progress of its acceleration is exerted in an instant at the working point, multiplied by the momentum depending on the proportion of the parts of the machine. It is thus that the coining press performs its office; nay, it is thus that the blacksmith forges a bar of iron. Swinging the great sledge hammer round his head, and urging it with force the whole way, this accumulated motion is at once extinguished by impact on the iron. It is thus also we drive a nail, &c. This accumulating power of a fly has occasioned many to imagine that a fly really adds power or mechanical force to an engine; and, not understanding on what its efficacy depends, they often place the fly in a situation where it only adds a useless burden to the machine. It should always be made to move with rapidity. If intended for a mere regulator, it should be near the first mover: and if it be intended to accumulate force in the working point, it should not be far separated from it. In a certain sense, a fly may be said to add power to a machine, because by accumulating into the exertion of one moment the exertions of many, we can sometimes overcome an obstacle that we never could have balanced by the same machine unaided by the fly. And it is this accumulation of force which gives such an appearance of power to some of our first movers. (See *Supplement Encyclopædia Britan.* art. *Machinery.*)

24. From these observations it is easy to pass to the con-

struction of elementary machines: and it will be advantageous to the young mechanist to see several of them collected into one point of view. For this purpose we have exhibited in plates XXXVIII. and XXXIX. (extracted from M. Hachette's ingenious *Traité Elémentaire des Machines,*) ten distinct series of simple machines, contrived for the purpose of changing or modifying motion. Thus, the 1st series exhibits different methods of changing the direction of continued rectilinear motion. The 2d relates to the conversion of continued rectilinear, to alternating rectilinear motion, and so on; the whole being readily classed thus.

Series.	Specimens.	Conversion of	Into
1	5	Continued rectilinear	Continued rectilinear
2		Continued rectilinear	Alternating rectilinear
3	16	Continued rectilinear	Continued circular
4	5	Continued rectilinear	Alternating circular
5	22	Continued circular	Alternating rectilinear
6	11	Continued circular	Continued circular
7	17	Continued circular	Alternating circular
8		Alternating rectilinear	Alternating rectilinear
9	10	Alternating rectilinear	Alternating circular
10	5	Alternating circular	Alternating circular

The construction of most of these machines will be evident from the respective diagrams. Others will be explained in the course of the present volume. We apprehend it would be highly useful for such persons as are beginning to exercise themselves in the construction of complex machines, to have the substance of these ten series drawn upon a large sheet of pasteboard, with spare compartments to be occupied by new contrivances in any one class, as they occur. Casting the eye over the whole would frequently suggest an ingenious and beneficial combination.

ON FRICTION, AND THE STIFFNESS OF ROPES.

25. Most of the propositions laid down in the first volume of this work have been conducted upon the supposition that all bodies are perfectly smooth, that they slide over one another without any friction, and that cords and ropes are perfectly flexible. But since there is no such thing as perfect smoothness in bodies, no machine can move without a mutual rubbing of

its parts, at all points of communication; and when we consider the mode of operation of the teeth of wheel-work, the wipers and lifts, the gudgeons of the different axes, &c. we shall see that *friction*, by which we mean the resistance a body meets with from the surface on which it moves, has considerable effect in retarding the motion of machines, or gives occasion for the exertion of much more power in order that the machine may move with the requisite velocity. Indeed in many machines, as polishing mills, grinding mills, boring and sawing mills, the ultimate task performed is either friction or very much resembles it. So that some knowledge of the nature of friction seems absolutely necessary, to enable us to apply the principles of the simple theory to any useful practical purpose.

Much attention has, therefore, been paid to this subject by many ingenious men; but as yet their labours have not greatly added to the stock of knowledge as to the real nature of friction: and although some ingenious theories have been deduced from the experiments which have already been made, they rest upon very limited hypotheses, and are of little, if any, actual utility. This being our opinion, the reader will not expect a minute exposition of the theory in this place. We shall merely present a single proposition, which tends to an obvious practical purpose, and does not require the admission of more than one new principle, viz. *that the friction varies nearly as the pressure.*

PROP. *A power which moves a body along a horizontal plane, acts with the greatest advantage when the line of direction makes an angle of about* $18\frac{1}{2}°$ *with the plane.* Let B (fig. 2. pl. I.) be the body which is to be moved along the horizontal plane BC, by a given power estimated in quantity and direction by BA. Demit the perpendicular AC: and let the given line $AB = 1 =$ radius, $AC = \sin ABC = x$, $BC = \sqrt{(1-x^2)} =$ the force moving the body horizontally. The power by its oblique action diminishes the pressure of the weight on the horizontal plane in the ratio of $1 : x$, therefore $Bx =$ that part of the pressure which is taken off, and the actual pressure $= B - Bx$. Let friction be $= \frac{m}{n}$th part of the weight or pressure: that is, let it be $= \frac{m}{n}B - \frac{m}{n}Bx$. Then the force requisite to move B horizontally must be equal to the horizontal force diminished by friction, or $= B(1-x^2)^{\frac{1}{2}} - \frac{m}{n}B + \frac{m}{n}Bx$. This is to be a minimum, or its fluxion $\frac{m}{n}B\dot{x} - \frac{Bx\dot{x}}{(1-x^2)^{\frac{1}{2}}} = 0$: hence we find $x = \frac{m}{(m^2+n^2)^{\frac{1}{2}}} =$ sine of the angle ABC. And if, as has been concluded from many experiments, $\frac{m}{n} = \frac{1}{3}$, then will $x = \frac{1}{\sqrt{10}} =$ sine of $18° 26'$ nearly.

If the plane along which the body is to be moved be inclined to the horizon, the sine of the angle which the line of direction or traction of the power makes with the plane, when it acts with the greatest advantage, will be nearly $= \frac{c}{c^2+9}$, c being the cosine of the angle of elevation to radius = unity.

26. The principle assumed in the investigation above is, however, by no means *general* in its application; as there are many circumstances which modify the operation of friction, and cause deviations from this law. These circumstances will be best learnt by reflecting upon some of the experiments which have been made relative to the friction of bodies in motion. Of such experiments we shall first describe those of Mr. Professor Vince, which were conducted with great care and ingenuity, and led to some important results. The object of this philosopher was to determine the following questions:

1. Whether friction be a uniformly retarding force?
2. What is the quantity of friction?
3. Whether the friction varies in proportion to the pressure or weight?
4. Whether the friction be the same on whichever of its surfaces a body moves?

(1.) With respect to the first of these questions, the author truly observes, that if friction be a uniform force, the difference between it and the given force of the moving power employed to overcome it must also be uniform; and that therefore the moving power, if it be a body descending by its own weight, must descend with a uniformly accelerated velocity, just as when there was no friction. The spaces described from the beginning of the motion will indeed be diminished in any given time on account of the friction; but still they must be to each other as the squares of the times employed.

(2.) A plane was therefore adjusted parallel to the horizon, at the extremity of which was placed a pulley, which could be elevated or depressed, in order to render the string which connected the body and the moving force parallel to the plane. A scale accurately divided was placed by the side of the pulley perpendicular to the horizon, by the side of which the moving force descended; upon the scale was placed a moveable stage, which could be adjusted to the space through which the moving force descended in any given time; which time was measured by a well-regulated pendulum clock vibrating seconds. Every thing being thus prepared, the following experiments were made to ascertain the law of friction.

(3.) *Exp.* 1. A body was placed upon the horizontal plane, and a moving force applied, which, from repeated trials, was

found to descend $52\frac{1}{2}$ inches in $4''$; for by the beat of the clock, and the sound of the moving force when it arrived at the stage, the space could be very accurately adjusted to the time: the stage was then removed to that point to which the moving force would descend in $3''$, upon supposition that the spaces described by the moving power were as the squares of the times; and the space was found to agree very accurately with the time: the stage was then removed to that point to which the moving force ought to descend in $2''$, upon the same supposition, and the descent was found to agree exactly with the time: lastly, the stage was adjusted to that point to which the moving force ought to descend in $1''$, upon the same supposition, and the space was observed to agree with the time. Now, in order to find whether a difference in the time of descent could be observed by removing the stage a little above and below the positions which corresponded to the above times, the experiment was tried, and the descent was always found too soon in the former, and too late in the latter case; by which the author was assured, that the spaces first mentioned corresponded exactly to the times. And, for the greater certainty, each descent was repeated eight or ten times; and every caution used in this experiment was also made use of in all the following.

Exp. 2. A second body was laid upon the horizontal plane, and a moving force applied which descended $41\frac{1}{4}$ inches in $3''$; the stage was then adjusted to the space corresponding to $2''$, upon supposition that the spaces descended through were as the squares of the times, and it was found to agree accurately with the time; the stage was then adjusted to the space corresponding to $1''$, upon the same supposition, and it was found to agree with the time.

Exp. 3. A third body was laid upon the horizontal plane, and a moving force applied, which descended $59\frac{5}{8}$ inches in $4''$; the stage was then adjusted to the space corresponding to $3''$, upon supposition that the spaces descended through were as the squares of the times, and it was found to agree with the time; the stage was then adjusted to the space corresponding to $2''$, upon the same supposition, and it was found to agree with the time; the stage was then adjusted to the space corresponding to $1''$, and was found to agree with the time.

Exp. 4. A fourth body was then taken and laid upon the horizontal plane, and a moving force applied, which descended 55 inches in $4''$; the stage was then adjusted to the space through which it ought to descend in $3''$, upon supposition that the spaces descended through were as the squares of the times, and it was found to agree with the time; the stage was then adjusted to the space corresponding to $2''$, upon the same sup-

position, and was found to agree with the time; lastly, the stage was adjusted to the space corresponding to $1''$, and it was found to agree exactly with the time.

Besides these experiments, a great number of others were made with hard bodies, or those whose parts so firmly cohered as not to be moved *inter se* by the friction; and in each experiment, bodies of very different degrees of friction were chosen, and the results all agreed with those related above; it was therefore concluded, that *the friction of hard bodies in motion is a uniformly retarding force.*

But to determine whether the same was true for bodies when covered with cloth, woollen, &c. experiments were made in order to ascertain it; when it was found in all cases, that the retarding force increased with the velocity; but, upon covering bodies with paper, the consequences were found to agree with those related above.

(4.) Having proved that the retarding force of all hard bodies arising from friction is uniform, the quantity of friction, considered as equivalent to a weight without inertia drawing the body on the horizontal plane backwards, or acting contrary to the moving force, may be immediately deduced from the foregoing experiments. For let M = the moving force expressed by its weight; F = the friction; W = the weight of the body upon the horizontal plane; S = the space through which the moving force descended in the time t expressed in seconds; $r = 16\frac{1}{12}$ feet; then the whole accelerative force (the force of gravity being unity) will be $\frac{M-F}{M+W}$; hence, by the laws of uniformly accelerated motions, $\frac{M-F}{M+W} \times rt^2 = S$, consequently $F = M - \frac{(M+W)\times S}{rt^2}$. To exemplify this, let us take the case of the last experiment, where $M = 7$, $W = 25\frac{3}{4}$, $S = 4\frac{7}{12}$ feet, $t = 4''$; hence $F = 7 - \frac{32\frac{3}{4}\times 4\frac{7}{12}}{16\frac{1}{12}\times 16} = 6{\cdot}417$; consequently the friction was to the weight of the rubbing body as $6{\cdot}4167$ to $25{\cdot}75$. And the great accuracy of determining the friction by this method is manifest from hence, that if an error of 1 inch had been made in the descent (and experiments carefully made may always determine the space to a much greater exactness) it would not have affected the conclusion $\frac{1}{600}$ part of the whole.

(5.) We come in the next place to determine, whether friction, *cæteris paribus*, varies in proportion to the weight or pressure. Now if the whole quantity of the friction of a body, measured by a weight without inertia equivalent to the friction drawing the body backwards, increases in proportion to its weight, it is manifest, that the retardation of the velocity of the

body arising from the friction will not be altered; for the retardation varies as $\frac{\text{Quantity of friction}}{\text{Quantity of matter}}$; hence, if a body be put in motion upon the horizontal plane by any moving force, if both the weight of the body and the moving force be increased in the same ratio, the acceleration arising from that moving force will remain the same, because the accelerative force varies as the moving force divided by the whole quantity of matter, and both are increased in the same ratio; and if the quantity of friction increases also as the weight, then the retardation arising from the friction will, from what has been said, remain the same, and therefore the whole acceleration of the body will not be altered; consequently the body ought, upon this supposition, still to describe the same space in the same time. Hence, by observing the spaces described in the same time, when both the body and the moving force are increased in the same ratio, we may determine whether the friction increases in proportion to the weight. The following experiments were therefore made in order to ascertain this matter.

Exp. 1. A body weighing 10 oz. by a moving force of 4 oz. described in 2″ a space of 51 inches; by loading the body with 10 oz. and the moving force with 4 oz. it described 56 inches in 2″; and by loading the body again with 10 oz. and the moving force with 4 oz. it described 63 inches in 2″.

Exp. 2. A body whose weight was 16 oz. by a moving force of 5 oz. described a space of 49 inches in 3″; and by loading the body with 64 oz. and the moving force with 20 oz. the space described in the same time was 64 inches.

Exp. 3. A body weighing 6 oz. by a moving force of $2\frac{1}{2}$ oz. described 28 inches in 2″; and by loading the body with 24 oz. and the moving force with 10 oz. the space described in the same time was 54 inches.

Exp. 4. A body weighing 8 oz. by a moving force of 4 oz. described $33\frac{1}{2}$ inches in 2″; and by loading the body with 8 oz. and the moving force with 4 oz. the space described in the same time was 47 inches.

Exp. 5. A body whose weight was 9 oz. by a moving force of $4\frac{1}{2}$ oz. described 48 inches in 2″; and by loading the body with 9 oz. and the moving force with $4\frac{1}{2}$ oz. the space described in the same time was 60 inches.

Exp. 6. A body weighing 10 oz. by a moving force of 3 oz. described 20 inches in 2″; by loading the body with 10 oz. and the moving force with 3 oz. the space described in the same time was 31 inches; and by loading the body again with 30 oz. and the moving force with 9 oz. the space described was 34 inches in 2″.

From these experiments, and many others which it is not necessary here to relate, it appears, that the space described is always increased by increasing the weight of the body and the accelerative force in the same ratio; and as the acceleration arising from the moving force continued the same, it is manifest, that the retardation arising from the friction must have been diminished, for the whole accelerative force must have been increased on account of the increase of the space described in the same time; and hence (as the retardation from friction varies as $\frac{\text{Quantity of friction}}{\text{Quantity of matter}}$) *the quantity of friction increases in a less ratio than the quantity of matter or weight of the body.*

(6.) We come now to the last thing which it was proposed to determine, that is, whether the friction varies by varying the surface on which the body moves. Let us call two of the surfaces A and a, the former being the greater, and the latter the less. Now the weight on every given part of a is as much greater than the weight on an equal part of A, as A is greater than a; if therefore the friction was in proportion to the weight, *cæteris paribus*, it is manifest, that the friction on a would be equal to the friction on A, the whole friction being, upon such a supposition, as the weight on any given part of each surface multiplied into the number of such parts, or into the whole area, which products, from the proportion above, are equal. But from the last experiments it has been proved, that the friction on any given surface increases in a less ratio than the weight; consequently the friction on any given part of a has a less ratio to the friction on an equal part of A than A has to a; and hence the friction on a is less than the friction on A, that is, the smallest surface has always the least friction.

As this conclusion is contrary to the generally received opinion, Mr. Vince thought it proper to confirm it by a set of experiments made with different bodies of exactly the same degree of roughness on their two surfaces.

Exp. 1. A body was taken whose flat surface was to its edge as 22 : 9, and with the same moving force the body described on its flat side $33\frac{1}{2}$ inches in $2''$, and on its edge 47 inches in the same time.

Exp. 2. A second body was taken whose flat surface was to its edge as 32 : 3, and with the same moving force it described on its flat side 32 inches in $2''$, and on its edge it described $37\frac{1}{2}$ inches in the same time.

Exp. 3. He took another body and covered one of its surfaces, whose length was 9 inches, with a fine rough paper, and by applying a moving force, it described 25 inches in $2''$; he then took off some paper from the middle, leaving only $\frac{3}{8}$ of

an inch at the two ends, and with the same moving force it described 40 inches in the same time.

Exp. 4. Another body was taken which had one of its surfaces, whose length was 9 inches, covered with a fine rough paper, and by applying a moving force it described 42 inches in 2″; some of the paper was then taken off from the middle, leaving only $1\frac{3}{8}$ inches at the two ends, and with the same moving force it described 54 inches in 2″; he then took off more paper, leaving only $\frac{1}{4}$ of an inch at the two ends, and the body then described, by the same moving force, 60 inches in the same time.

In the two last experiments the paper which was taken off the surface was laid on the body, that its weight might not be altered.

Exp. 5. A body was taken whose flat surface was to its edge as 30 : 17; the *flat* side was laid upon the horizontal plane, a moving force was applied, and the stage was fixed in order to stop the moving force, in consequence of which the body would then go on with the velocity acquired until the friction had destroyed all its motion; when it appeared from a mean of 12 trials that the body moved, after its acceleration ceased, $5\frac{2}{5}$ inches before it stopped. The *edge* was then applied, and the moving force descended through the same space; and it was found, from a mean of the same number of trials, that the space described was $7\frac{1}{3}$ inches before the body lost all its motion, after it had ceased to be accelerated.

Exp. 6. Another body was then taken whose flat surface was to its edge as 60 : 19, and by proceeding as before on the flat surface, it described, at a mean of 12 trials, $5\frac{1}{8}$ inches, and on the edge $6\frac{11}{24}$ inches, before it stopped, after the acceleration ceased.

Exp. 7. Another body was taken whose flat surface was to its edge as 26 : 3, and the spaces described on these two surfaces, after the acceleration ended, were, at a mean of ten trials, $4\frac{3}{7}$ and $\frac{7}{10}$ inches respectively.

From all these different experiments it appears, that the smallest surface had always the least friction, which agrees with the consequence deduced from the consideration that the friction does not increase in so great a ratio as the weight; we may therefore conclude, that *the friction of a body does not continue the same when it has different surfaces applied to the plane on which it moves, but that the smallest surface will have the least friction.*

To the experiments instituted by Mr. Ferguson and others, from which conclusions have been drawn so different from these, this author makes the following objections: It was their

object to find what moving force would *just* put a body at rest in motion; and having, as they thought, found it, they thence concluded, that the accelerative force was then equal to the friction. But it is manifest, as Mr. Vince observes, that any force which will put a body in motion must be *greater* than the force which opposes its motion, otherwise it could not overcome it; and hence, if there were no other objection than this, it is evident, that the friction could not be very accurately obtained: but there is another objection which totally destroys the experiment so far as it tends to show the quantity of friction, which is the strong cohesion of the body to the plane when it lies at rest; and this is confirmed by the following experiments. 1st, A body of $12\frac{3}{4}$ oz. was laid upon an horizontal plane, and then loaded with a weight of 8lb. and such a moving force was applied as would, when the body was just *put* in motion, continue that motion without any acceleration; in which case the friction must be just equal to the accelerative force. The body was then stopped, when it appeared, that the same moving force which had *kept* the body in motion before would not *put* it in motion, and it was found necessary to take off $4\frac{1}{2}$ oz. from the body before the same moving force *would* put it in motion; it appears, therefore, that this body, when laid upon the plane at rest, acquired a very strong cohesion to it. 2dly, A body whose weight was 16 oz. was laid at rest upon the horizontal plane, and it was found that a moving force of 6 oz. would just *put* it in motion; but that a moving force of 4 oz. *would*, when it was just put in motion, *continue* that motion without any acceleration, and therefore the accelerative force must *then* have been equal to the friction, and not when the moving force of 6 oz. was applied.

From these experiments therefore it appears, how very considerable the cohesion was in proportion to the friction when the body was in motion; it being, in the latter case, almost $\frac{1}{3}$, and in the former it was found to be very nearly equal to the whole friction. All the conclusions therefore deduced from the experiments, which have been instituted to determine the friction from the force necessary to *put* a body in motion (and very few have been described but upon such a principle) have manifestly been totally false; as such experiments only show the resistance which arises from the cohesion and friction conjointly.

Mr. Vince concludes this part of the subject with a remark upon art. 5. "It appears (says he) from all the experiments which I have made, that the proportion of the increase of the friction to the increase of the weight was different in all the different bodies which were made use of; no general rule there-

fore can be established to determine this for *all* bodies, and the experiments which I have hitherto made have not been sufficient to determine it for the *same* body."

Such are the results of Mr. Vince's ingenious experiments. He founds upon them a theory which the curious reader may peruse in the *Philosophical Transactions*, Vol. 75. or Nos. 65, 66. of *Tilloch's Philosophical Magazine*, but which is not inserted here, as it does not seem readily applicable to any practical cases.

27. An ingenious engineer, Mr. John Southern of Birmingham, made a series of experiments upon mills used for turning grindstones, with a view of corroborating Mr. Vince's position that *Friction is a uniform retarding force.* And these experiments are the more worthy of notice as they were made on *heavy* machinery, with considerable variation of velocity of the rubbing surface, and great spaces rubbed over: the weight which caused the friction being upwards of 33 cwt., the velocity of the rubbing surfaces 4 feet per second at the greatest, and the length of surface rubbed over about 1000 feet at a medium. These experiments seem to confirm the opinion that friction is a uniform resistance, at least where the rubbing surface moves with a velocity of from 9 inches to 4 feet per second; and Mr. Southern concludes from them, that in favourable cases it does not exceed *the fortieth part of the pressure or weight that occasions it.*

The experiments from which these inferences are deduced, are described in No. 66. of the Philosophical Magazine just referred to.

28. *M. Coulomb* has an extensive paper on the subject of Friction, in vol. 10. "*Des Memoires des Savants étrangers*;" where he describes his experiments at considerable length, and deduces from them an elaborate theory. We cannot here enter into the detail of all these experiments: but shall merely state M. Coulomb's principal results.

This author's conclusions are widely different from Mr. Vince's in one important particular: for he asserts that *(cæteris paribus) the friction is proportional to the pressure.* The mean ratios of friction to pressure, given by M. Coulomb's experiments for different kinds of wood, are as follow, the pressure being denoted by unity:

Oak against oak . . .	0·43
Oak against fir	0·65
Fir against fir	0·56
Elm against elm . . .	0·47

the friction being made in the direction of the threads or fibres of the wood. But when the friction is made *across* the grain

of the wood, or so that the direction of the fibres forms a right angle with that of the motion, the friction is less than in the former case, but still in a constant ratio to the pressure; the results being then as below:

Oak against fir	0·158
Fir against fir	0·167
Elm against elm . . .	0·100

These ratios are constant quantities, not depending upon the velocities, except in the case of elm when the pressures are very small, for then the friction increases sensibly with the velocity.

M. Coulomb gives the following general summary.

"(1.) The friction of wood sliding over wood (both being dry) opposes after a sufficient time of quiescence a resistance proportional to the pressure; that resistance sensibly increasing in the first instants of repose: but after some minutes it usually arrives at its maximum or its limit.

"(2.) When wood glides dry over wood with any velocity whatever, the friction is still proportional to the pressure; but its intensity is much less that that which is experienced in detaching the surfaces after some minutes of rest; it has been found, for example, that the force necessary to detach and produce a sliding motion in two surfaces of oak after some minutes of quiescence, is to that necessary to overcome the friction when the surfaces have obtained any degree of velocity whatever, nearly as 9 to 2.

"(3.) The friction of metals sliding over metals, without oiling, is also proportional to the pressures; but its intensity is the same, whether the surfaces are detached after having been any time in repose, or whether they preserve any uniform velocity whatever.

"(4.) Heterogeneous surfaces, such as woods and metals sliding the one over the other, without oiled surfaces, give for their friction results very different from the preceding ones: for the intensity of their friction relatively to the time of repose increases slowly, and does not attain its limit till after four or five days, and sometimes more; instead of which, in metals the limit is attained in an instant, and in wood in a few minutes: this augmentation is even so slow that the resistance due to the friction in insensible velocities is almost the same as that which we must surmount in moving or detaching the surfaces after three or four seconds of rest. And this is not all: in wood gliding unoiled over wood, and in metals sliding over metals, the velocity has very little influence upon the friction; but here the friction increases very sensibly in proportion as the velocities are augmented; in such manner that the friction in-

creases nearly according to an arithmetical progression, when the velocities increase in a geometrical progression."

The ratio of the friction to the pressure (1) when oak was made to slide over iron, was found, from forty experiments, to be as here stated: when the velocity was almost insensible, ·0894, ·0773, ·0785, and ·0786: when the velocity was about a foot per second, ·1698, ·1722, ·1817, and ·1573.

29. When metals slide upon wood done over with grease, the friction, says M. Coulomb, "appears much softened, and we may produce insensible velocities with degrees of traction less considerable than in all the other species of friction; but when the velocities have been a little augmented, we have found that the friction increases greatly with respect to the velocity, as was the case when we made unoiled metals slide upon wood; and we have, for the relation of the augmentation of velocities and the degree of traction which produced that augmentation, nearly the same law with that we sought to determine in the friction of metals sliding *dry* upon wood: but if the greasing be not renewed at each experiment, it coagulates, changes its nature, and the friction successively augments.

"When the surfaces are done over with tallow, the ratio of the friction to the pressure is greater under pressures of about 50 pounds, than under greater pressures.

"With coatings (*enduits*, plasters) of cart-grease, the friction is never less than $\frac{1}{9}$ of the pressure. Its resistance depends upon the consistence of the coating, and the friction augments sensibly as this coating is softer. When the surfaces are done over with tallow, and are of great extent, the friction corrupts or changes the nature of the tallow, and augments sensibly as we continue the motion without renewing the coating: yet it is always found less than $\frac{1}{8}$ of the pressure. But when the tallow is dissolved to an oil, this effect is less sensible."

M. Coulomb's experiments on the friction of *axes* will be described farther on.

On comparing the results of Mr. Vince's experiments with those of M. Coulomb's, already referred to, it will be seen that our knowledge on this branch of the subject is very far from being so certain and satisfactory as is desirable. We may, however, now deduce a few practical inferences from the preceding articles.

(1.) Friction is diminished by making the surfaces smooth which move upon each other. But there is a limit to this smoothness; for the surfaces may be so highly polished as to render the attraction of cohesion very sensible.

(2.) Friction is diminished by anointing the rubbing surfaces

with some unctuous matter. Thus, in wood acting against wood, olive oil reduces the friction to nearly its half, and metals oiled have less friction than when polished.

(3.) Friction is diminished by diminishing the surfaces in contact. But this has a limit: for if the moving surface be very thin, and the other soft, the former will plough a groove in the latter, and thus have the friction increased.

(4.) Friction is diminished by disposing the parts of a machine in such a manner, that the ratio of the velocity of the parts which rub against each other to the velocity of the power, may be as small as possible.

(5.) Friction is greatly diminished by causing the body to roll instead of sliding along the surface. This is in fact a distinct species of friction, and will come under consideration more fully soon.

(6.) Hence in many machines, lest the friction should employ a great part of the power, care is to be taken that no part of the machine *slide* along another if it can be avoided; but rather that the parts should roll or turn upon each other. With this view it will be proper to lay the axes of cylinders, &c. not in a groove or concave matrix, as is usual, but upon a horizontal bar with two vertical pieces to keep such axes from rolling off, or, between little wheels called *friction* wheels, moveable on their respective axes: for, by this contrivance, the friction is transferred from the circumference of those wheels to their pivots. And in like manner the friction may be still further diminished by making the axes of those wheels rest upon other friction wheels that turn round with them. For the same reason friction balls or rollers have been placed within the naves of carriage wheels; and in Mr. Garnett's patent for an improved manner of applying friction wheels to any axis, as of carriages, blocks, pulleys, scale-beams, &c. the wheels or rollers are kept always at the same distance by connecting rods or bars.

(7.) Friction is diminished by causing the surface of one kind of substance to run not upon the same kind of matter, but a surface of another material equally polished. Thus, pivots of steel meet with less friction when they slide in grooves of copper, than when the grooves are of steel also.

(8.) As to friction in the mechanical powers: 1. The simple lever has no such resistance, unless the place of the fulcrum is changed during the operation. 2. In the wheel and axle, the friction on the axis is nearly as the weight upon it, the diameter of the axis, and the angular velocity. This sort of friction, however, is very small. 3. The friction of the pulley is very considerable when the sheaves rub against the blocks. 4. There is also very great friction in the screw: if the screw has a square

thread it will raise a weight more easily than one with a triangular thread: but in most if not all screws the friction is equal to the power. 5. In the inclined plane the friction varies according as the body rolls or slides; the friction in the latter case being far the greatest. 6. In the wedge the friction is at least equal to the power, since the wedge retains any position it is driven into.

29. A. The memoir of the same philosopher on the friction of pivots, is inserted among the Memoirs of the Paris Academy for the year 1790. Though it has been so long published, it is scarcely known even in France: yet as the experiments described are very interesting, and furnish some important results, it will be right to give an account of them.

Bodies which are made to turn upon pivots are usually suspended by means of a cheek, socket, or collar, of very hard matter. The collar has its cavity of a conic form, and terminated at its summit by a little concave segment, whose radius of curvature is very small. The point of the pivot which is sustained by this collar forms at its summit a little convex surface, whose radius of curvature should be still smaller than that of the extremity of the cheek. Experience evinces that the curvature of the bottom of the socket is irregular, and that the friction of a collar of agate on which a pivot turns, is frequently five or six times more considerable than the *momentum of friction* of a well-polished plane of agate on which the same pivot turns.

These considerations induced M. Coulomb to employ in the course of his experiments, not a cheek or a socket, but a well-polished plane, to support the body on the point of a pivot. To prevent the body from sliding he took care that its centre of gravity should be very low, with respect to the point of suspension: he then made the body to whirl or spin about its pivot, by impressing upon it a rotatory motion. By means of a seconds watch, he observed exactly the time employed by the body in making the first four or five turns, and he thence deduced easily a mean turn to determine the primitive velocity: after this he counted the number of turns which the body made before it stopped.

Coulomb took a glass bell of 48 lines in diameter and 60 lines in height, which weighed 5 ounces. He placed it on the point of a pivot; and after giving it successive degrees of velocity about that pivot, he observed very exactly the time that it employed to make the first turn, which gave him for the mean velocity that which answered to the half of such first turn. He then estimated the number of turns made by the bell before it stopped: the results were as below—

1*st Trial.* The bell made one turn in 4″, and came to rest after $34\frac{1}{10}$ turns.

2*d Trial.* The bell made one turn in $6\frac{1}{4}''$, and stopped after $14\frac{1}{10}$ turns.

3*d Trial.* The bell made one turn in 11″, and stopped after $4\frac{6}{10}$ turns.

Now if b denote the primitive velocity, x the space described between the commencement and the end of the motion, A the constant momentum of the retarding force; $\int\frac{\mu r^2}{a}$ the sum of the products of every particle μ, by the square of its distance r from the axis of rotation, divided by the quantity a, measuring the distance from the axis of rotation to the point whose primitive velocity is b, it is easy to find the following analytical expression for the constant momentum of the *vis retardatrix*, viz.

$$\mathrm{A} = \frac{b^2}{2\mathrm{x}}\int\frac{\mu r^2}{a}.$$

But, because in the three preceding trials, the same bell was employed, the quantity $\int\frac{\mu r^2}{a}$ is the same: $\frac{b^2}{\mathrm{x}}$ must therefore be a constant quantity if A be constant, and reciprocally. But in each trial there was reckoned the time employed by the apparatus in performing an entire revolution. The mean velocity, or the velocity due to the half of each first revolution, will, therefore, be measured by the circumference run over. The space described up to the end of the motion, will be measured by the number of turns run through from the instant where the mean velocity was determined until the end of the motion. Thus by computing from the data furnished by the three trials, we may form the following table:

1*st Trial.*	1 turn in 4″,	stops at $34\frac{1}{10}$ turns,	whence results $\frac{b^2}{\mathrm{x}}$	$=\frac{1}{547}$
2*d Trial.*	$6\frac{1}{4}''$	$14\frac{1}{10}$		$=\frac{1}{550}$
3*d Trial.*	11″	$4\frac{6}{10}$		$=\frac{1}{557}$

This experiment, then, shows unequivocally that the quantity $\frac{b^2}{\mathrm{x}}$, and consequently the quantity A which expresses the momentum of friction, are constant quantities, whatever be the primitive degree of velocity; and that, consequently, the velocity has not any influence upon the *resistance* due to the friction of pivots, which from this experiment is necessarily proportional to a function of the pressure.

When this experiment is made in a vacuum, a much less heavy body may be employed, and of any form whatever, and the same result will be obtained.

In other experiments Coulomb bent a brass wire of 9 inches in length; the parallel branches were 24 lines distant from one another; the part of the wire curved in the form of a semicircle which joined the two branches was about 3 inches long; and the two vertical and parallel branches were also each 3 inches long. To the extremity of each vertical branch was attached by means of wax a piece of metal, and there was fixed, in like manner, in the middle of the concave part of the wire, to serve for the cheek or bush, a small well-polished plane of different substances on which the friction of the point of the pivot was to be determined: finally, there was fixed to the summit of a support a little needle of tempered steel, and whose point it was necessary to render more or less fine, rounded, or obtuse, according to the nature of the cheeks, and to the pressure which they were to experience. The extremity of the needle first used by Coulomb, appeared, when examined by a microscope, to form a conic angle of 18 or 20 degrees. The friction of this needle against well-polished planes of granite, agate, rock crystal, glass, and tempered steel respectively, was tried; and the result, taking in each experiment the mean quantity represented by $\frac{b^2}{x}$ (a quantity which was always found to vary between very narrow limits), gave the momentum of friction of the point of the needle against the planes of granite, agate, &c. respectively, in the ratio of the fractions $\frac{1}{1029}$, $\frac{1}{847}$, $\frac{1}{784}$, $\frac{1}{579}$, $\frac{1}{487}$; so that the momentum of friction of the plane of granite being represented by unity, we shall have for the momentum of the friction of rotation relative to the other substances as below: friction of granite, 1; of agate, 1·214; of rock crystal, 1·313; of glass, 1·777; of steel, 2·257.

Coulomb likewise employed himself during these experiments, in determining the more or less acute form which should be given to the points of the pivots. To this end he caused to be successively rounded into cones of greater or less acuteness, the extremity of a steel needle, that it might thence appear whether the change of figure had any influence upon the friction. Thus he found that, under a certain charge, the point of the pivot being shaped to 45 degrees, the quantity $\frac{b^2}{x}$ was, for granite, $\frac{1}{2500}$; agate, $\frac{1}{2100}$; glass, $\frac{1}{1400}$; tempered steel, $\frac{1}{2000}$.

Coulomb then gave to the point a more acute form, so that the angle of the cone which terminated it could not be more than 6 or 7 degrees; and he found, still retaining the same charge or pressure as before, that the quantity $\frac{b^2}{x}$ was, for agate, $\frac{1}{800}$; glass, $\frac{1}{450}$; tempered steel, $\frac{1}{230}$.

Comparing from these, and other experiments, the momentum of friction of rotation of the point of different pivots against a plane of agate, he found that the quantity $\frac{b^2}{x}$ which varies as that momentum, was, for a pivot of 45°, $\frac{1}{2100}$; a pivot of 15°, $\frac{1}{1200}$; a pivot of 6°, $\frac{1}{800}$.

After this, Coulomb varied the charge in his experiments, and determined the relative momentum of friction of pivots under different pressures. But without going further into detail, we may give the following as the principal deductions from the whole.

1. That the friction of pivots is independent of the velocities, being merely as a function of the pressure.

2. That the friction of granite is less than that of glass.

3. That the figure of the point of the pivot, as to acuteness, affects the quantity of friction; in such manner that when we cause to whirl upon the point of a needle, a body weighing more than 5 or 6 drams, the most advantageous angle for that point appeared to be from 30° to 45°; under a less pressure, the angle might be progressively diminished, without the friction being perceptibly augmented: it may even without great inconvenience be reduced to 10° or 12° with good steel, when the charge does not exceed 100 grains: an important consideration in the suspension of light bodies upon cheeks or sockets.

These rules may be useful to the makers of chronometers.

29 B. In some cases, nay, in several, the object of the mechanist is not to destroy or to diminish friction; but to *create* it. Friction furnishes the most simple and efficacious means of checking and destroying motion. Thus, in complex machines, friction is augmented by transferring it from the centre to the circumference of a wheel; but simpler methods are often employed, as when the motion of a ship is checked by the rubbing of a rope against the circumference of a post about which it is coiled.

Professor Leslie has thus examined the nature of this species of friction. Let a flexible cord PABCQ wind about the circumference of a pulley or cylinder, of centre O, radius OA, OB, &c. so as to be in contact with a part of it, and let a weight P, at one end of the cord, be drawn by a force Q at the other end, the cord rubbing against the portion ABC of the cylinder. [The figure may at once be sketched from the description.] The pressure of the cord against the cylinder at any point will be in proportion to the degree of its inflexion. Conceive the arc ABC to be divided into elementary portions, then will the tension of the cord in the direction of a tangent as at B, be to the pressure of the element bB, as the radius OB to bB. If $1 : m$

denote the ratio of the pressure of $b\text{B}$ to its friction $\frac{m \cdot b\text{B}}{\text{OB}}$ will express the proportional increase of tension from b to B. Suppose the successive tensions to be represented by P, P′, P″, &c. then $\text{P}' - \text{P} = \text{P}\frac{m \cdot b\text{B}}{\text{OB}}$, $\text{P}'' - \text{P}' = \text{P}' \cdot \frac{m \cdot b\text{B}}{\text{OB}}$, &c. consequently, the hyp. log. of $\frac{\text{Q}}{\text{P}} = \frac{m \cdot \text{ABC}}{\text{OB}} = m \cdot$ angle AOC. Hence, assuming equal angles about the centre O, the corresponding tensions will constitute a geometrical progression. Thus, if ABC were a quadrant, and a weight P of 1 pound balanced a traction of 2 pounds at C, it would uphold 4 pounds at the end of the semicircumference, 8 pounds at 270°, 16 pounds at a complete revolution; 256 lbs., 4096 lbs. and 65536 lbs. at the end of 2, 3, and 4 convolutions. Thus it appears that the augmentation of friction is extremely rapid; and that after a very few coils of the cord a small weight will suffice to support a most enormous load.

The practical result differs only in a small degree from this result of an assumed theory; and it is modified exceedingly by a change in the magnitude of the cylinder. Hence, the firmness procured by the wrapping of cordage; and hence is derived the principle of some fire-escapes and other engines, in which the celerity of descent from a great height is diminished, and the shock against the ground rendered comparatively gentle and safe. An analagous principle occurs in the next inquiry.

30. Since cords and ropes are not perfectly flexible, it becomes necessary in estimating the advantages of pulleys, capstans, &c. to make some allowance for this want of flexibility: in this case we may have recourse to a theory which is far more satisfactory than any which has yet been invented with regard to friction, and which accords far better with experiment. The most useful formulæ may be deduced in a very small compass. Thus, let $\text{AC} = \text{CB} = r$, the radius of a pulley (fig. 3. pl. I.) and two weights W and Q in equilibrio: if W should prevail, it is obvious that the cord DQ becomes in the upper part bent so as to fit to the groove of the pulley, and in the lower part bent inwards so as to fall into the vertical bW: if the cord be tolerably flexible, the curving is pretty regular from B almost down to W: but if the cord be very rigid, BEW and ADQ are found to be nearly straight lines, but neither of them vertical; the weight Q being found to hang vertically below some point as a, making Ca greater than CA, and the weight W hanging below some point b where Cb is less than CB. So that as the arm of the lever at which one of the forces acts is become greater, and that of the other less than r, the condition of equilibrium is no longer $\text{W} = \text{Q}$.

When the cord is only moderately rigid, as in most practical cases, the distance Bb is always found so extremely small that it may be safely neglected in the discussion; that is, we need in such cases pay no regard to the want of flexibility in the part BEW corresponding to the weight W which is supposed to prevail; but merely inquire into that of the part ADQ by which the other weight is suspended. Hence, if we put Aa $= q$, the condition of equilibrium will be expressed thus:

$$Wr = Q\,(r + q).$$

From this it results, that if $W - Q$ be the magnitude by which we should augment the power, that it may be on the point of prevailing; and if we have regard to the stiffness of the cord, this magnitude will be $W - Q = Q \cdot \frac{q}{r}$. Consequently, *to introduce the consideration of the stiffness of the cord employed in a machine, we have only to suppose that the arm of the lever at which the resistance acts is greater than it really is, by a determinate quantity* q.

It remains, then, to ascertain this quantity q: in order to which, it may be observed that a cord resists, on two accounts, the efforts which are made to bend it. The first is due to the tension of the cord, and is proportional to it, it will therefore be $= bQ$; the second is due to its warping or twisting, and we may represent by a the force employed to overcome it. Here a and b are, as is manifest, variable coefficients. Thus, for one and the same cord, $a + bQ$ may represent the force required to bend it: but, if the cord be changed, the diameter d will be different, and we may conclude that, *cæteris paribus*, the force which must be employed will be proportional to a certain power n of d; for the force necessary to bend a cord will increase with its diameter: this power will decrease on the contrary with the radius r of the pulley; therefore $\frac{d^n}{r}(a + bQ)$ may represent the force necessary to overcome the stiffness of the cord; n being as yet an indeterminate quantity. This value being the augmentation which must be given to the force or weight W that it may be on the point of prevailing over the resistance Q, must, from what is before shewn, be equal to $Q\,\frac{q}{r}$. Thus we have

$$d^n\,(a + bQ) = Qq, \text{ or } q = \frac{d^n}{Q}(a + bQ) \quad . \quad . \quad (A).$$

This equation, it is true, is only furnished by general considerations, and not by a rigorous investigation: it contains, moreover, the unknown coefficients n, a, and b, varying for different cords. But there is a simple method of finding these coefficients, and of assuring ourselves that the expression is sufficiently exact in practice.

31. Choose any cord, and after bending it along the groove of a pulley, as the cord QDABEW (fig. 3.), attach to it two equal weights, and augment one of them till it is just on the point of prevailing so as to give motion to the system, marking the difference of the weights. Make a similar experiment four times, taking as many different values of W and of Q, also of r: so shall there be obtained four values of $W - Q$, that is to say, of $\frac{d^n}{r}(a + bQ)$, which will furnish four equations. Putting e, f, g, h, these values, and denoting by r, r', r'', r''', the several radii of the pulleys, and Q, Q', Q'', Q''', the weights employed in their turns, we shall have

$$e = \frac{d^n}{r}(a + bQ) \quad . \quad . \quad . \quad . \quad f = \frac{d^n}{r'}(a + bQ')$$

$$g = \frac{d^n}{r''}(a + bQ'') \quad . \quad . \quad . \quad . \quad h = \frac{d^n}{r'''}(a + bQ''')$$

Of these equations the three first serve to discover the values of n, a, and b; and the last enables us to assure ourselves whether the formula (A) has the accuracy we wish.

32. As to experiments on the rigidity of ropes and cords, we know none of any great importance and extent besides those of M. Coulomb. These experiments were made with two kinds of apparatus, one contrived by M. Amontons, the other by Coulomb himself: the experiments made by means of one instrument corroborated the results of those made by the other: but we shall here merely describe the experiments by means of Coulomb's apparatus, which we prefer because it was contrived to ascertain at the same time that kind of friction which is occasioned by the rolling of cylinders upon horizontal planes.

The apparatus consists of two tressels of 6 feet in height, and sufficiently solid and firm, on which there are laid two pieces of squared wood; upon these two pieces of wood are fixed two rulers of oak well planed, DD, D′D′ (fig. 4. pl. I. nos. 1, 2.), and polished with a little fish-skin: then two cylinders of lignum vitæ are procured, one of 6 inches diameter, the other of two inches; together with several cylinders of elm from 2 to 12 inches in diameter.

These things prepared, in order first to find the friction of the rollers, they are laid horizontally upon the two rulers of oak, and crossing their directions perpendicularly, as represented in fig. 4. no. 2. the rulers being in a perfectly horizontal position: then suspend on each side of the roller in use a weight of 50 lbs. with very fine and flexible packthread; or indeed by means of several such threads distributed over the roller, and charged each with 50 lbs. on each side, produce upon the rulers any determinate pressure; and ascertain by the aid of little coun-

terweights suspended alternately on the different sides of the roller what will be the force necessary to give it a motion barely sensible.

The friction of the rollers being estimated by the preceding method, it will be easy to allow for it, when instead of the very flexible packthread, the cords or ropes of which the stiffness is to be determined are substituted. And this new determination will be made in the same manner as with respect to the nascent friction by suspending the little weights alternately on each side of the roller, so that they shall give it a motion just perceptible.

It is obvious to remark that this method of estimating the effects of the rigidity of cords will furnish results directly applicable to the preceding formulæ: for the weights which produce the very small motion in the cylinders will be precisely equal to the augmentation of the resistance arising from the stiffness of the cord, estimated in the direction of that portion of the cord to which the resistance is applied that represents the usual effect of the machine.

33. We shall first exhibit the results of M. Coulomb's experiments, on the second species of friction, produced by rollers of lignum vitæ of 6 and of 2 inches diameter.

Charge of the rollers, their weight being comprised.	Weights which produce an extremely slow motion, the diameter of their rollers being	
	6 inches	2 inches
100 lbs.	0·6	1·6
500	3·0	9·4
1000	6·0	18·0

From this table M. Coulomb infers that the friction of cylinders which roll upon horizontal planes is directly as the pressures, and inversely as the diameters of the rollers. He also found that greasing the surfaces did not here cause any sensible diminution in the friction.

Note. The foot and the pound spoken of throughout these experiments are those of the ancient Paris standard: we have not reduced them to English measures, since the deductions founded upon the experiments do not render this necessary.

Rollers of elm produced a friction of about the $\frac{2}{5}$ greater than lignum vitæ. And under small pressures the friction was rather greater than would result from the law of friction being proportional to the pressure.

34. We shall next present the results of Coulomb's experiments upon the rigidity of cords, and different rollers between 2 and 12 inches in diameter; the deduction for the friction is

stated in the table, and a comparative column exhibits the rigidity deduced from the experiments made with the apparatus of Amontons. The cords were of three kinds: No. 1, of 6 threads in a yarn, or 2 in a strand, the circumference 12½ lines, and weight of a foot in length 4½ drams. No. 2, of 15 threads in a yarn, or 5 in a strand, circumference 20 lines, weight of a foot in length 12½ drams. No. 3, of 30 threads in a yarn or 10 in a strand, circumference 28 lines, weight of a foot in length 24½ drams.

No. of experiments.	Cords used in the experiments.	Kinds of wood diameter and weight of the rollers.	Weights hung on each side the roller in lbs.	Addition. weight to surmount friction of roller and stiffness of cords.	Total charge of the rulers which support the roller.	Friction of the roller.	Stiffness of the Cord. Valued by Coulomb's apparatus.	Stiffness of the Cord. Valued by Amonton's apparatus.
1	Cord No. 3. of 30 threads in a yarn.	Elm 12 inches diameter, weight 110 lbs.	100	5 lbs.	315	1·5	3·5	4·4
			300	11	721	3·6	7·4	10·4
			500	20	1130	5·6	14·4	16·4
2	Idem.	Elm 6 inches diameter, weight 25 lbs.	200	18	443			
3	Idem.	Guiacum 6 inches diameter, weight 50 lbs.	200	16	466	2·8	13·2	14·8
4	Idem.	Guiacum 2 inches diameter, weight 42½ lbs.	25	11	65½			
			200	52	456½			
5	Cord No. 2. of 15 threads in a yarn.	Guiacum 6 inches diameter, weight 50 lbs.	25	1¼	101¼			
			100	6	256			
			200	11	461	2·8	8·2	7·6
			500	24	1074	6·4	17·6	17·8
6	Cord No. 1. of 6 threads in a yarn.	Idem.	100	3	253			
			200	6	456	2·7	3·3	3·1

From this table it will be seen that the method of Amontons and that of Coulomb furnish nearly the same results: M. Coulomb ascribes the differences where greatest to the circumstances

of the cords having been more used previous to their being taken for one kind of experiment than for the other.

35. M. Coulomb, before he commenced the experiments upon the friction of axes, caused the pulley to turn on its axis during such a time and with such a velocity as was necessary to enable the surfaces in contact to acquire all the polish and glibness of which they were susceptible. The chief object held in view in the experiments of which we now speak was to determine the friction of the axis of machines in motion. M. Coulomb therefore caused the suspended weights to run over a space of 6 feet, and to measure separately by half seconds the time employed to run over the first three feet, and that occupied in running over the last three feet. The following table contains the results of experiments on the friction of axes of iron in boxes of copper: the axis used was 19 lines in diameter, and had a play of $1\frac{3}{4}$ lines in the copper box, the pulley was 144 lines in diameter, and weighed 14 pounds.

No. of experiments.	Kind of cord used.	Kind of greasing.	Weight used to bend the cord over the pulley.	Weight hung on each side of the pulley.	Additional weight to move the pulley.	Motion of the weight suspended on each side of the pulley.	Pressure on the axis.	Friction reduc. to surface of axis.	Ratio of friction to the pressure.
1	Very flexible thread of 3 lines circumference.	Friction without greasing.	0·0	103	6	Slow and irregular.	226	42	0·186
2	Cord No. 1. of 6 threads in a yarn.	Idem.	1·5	200	10·5	Slow and irregular.	424	65	0·153
					13·5	The first 3 ft. fallen through in 6″, the last 3 in 3″.			
3	Idem.	Idem.	3·0	400	21	Slow but continual.	825	130	0·156
					28	The first 3 feet described in 5″·5, the last 3 in 2″·5.			
					39	First 3 ft. described in 3″, the last 3 in $1\frac{1}{2}$″.			
4	Very flexible thread, of 2 lines circumference.	tallow.	0·0	100	2·5	Slow but continual.	216·5	17·5	0·808
					6	The first 3 feet described in 3″·5, the last 3 in 1″·5.			
5	Cord No. 1. of 6 threads in a yarn.	Idem.	1·5	200	6·5	Slow but continual.	420	36	0·086
					10·0	The first 3 feet described in 3″·5, the last 3 in 1″·5.			
6	Idem.	Idem.	3·0	400	13	Slow and continual.	827	72	0·087
					18	The first 3 feet described in 5″·5, the last 3 in 2″.			
					24	First 3 feet in 3″. Last 3 feet in 2″.			

7	Thread of 2 lines in circumference.	Cart grease.	0·0	50	2·5	Slow and continual.	117	17·5	0·15
8	Idem.	Idem.	0·0	100	3·7	Idem	218	26	0·119
9	Idem.	Idem.	0·0	150	5·7	Idem .... Slow and uncertain.	320 218	40 26	0·125 0·119
10	Cord No. 1. of 6 threads in a yarn.	Idem.	0·7	100	4·3 9	first 3 feet in 3″, last 3 feet in 1½″.			
11	Idem.	Idem.	1·5	200	8·5 14 20	Uncertain. first 3 feet in 4″, last 3 feet in 2″. all 6 feet in 3″·5.	422	50	0·118
12	Idem.	Idem.	3·0	400	17 22 28	Uncertain. first 3 feet in 6″·5, last 3 feet in 2″·5. first 3 feet in 4″, last 3 feet in 1″·5.	831	101	0·121
13	....	The cart greas.ofprec. exp. wiped, the pores of the metal remained unctuous.	....	....	....	....	From 200 to 1200 lbs.	....	0·127
14	....	The surface fresh done with oil.	....	....	....	....	....	....	0·127 0·133
15	....	The greasing not renewed of a long time though the machine had been much used.	....	....	....	....	....	....	0·133

The weights employed to bend the cord, and which are contained in the fourth column, were calculated from the tensions expressed in the 5th column, by means of the formulæ already given, and the results of some previous experiments. These weights being subtracted from those of the 6th column, which put the system in motion, leave the weights employed in overcoming the friction. These latter weights acting at a distance from the centre of rotation equal to the sum of the radii of the pulley and the cord: the friction which is exerted upon the axis, and which in the case of a very slow motion may be considered as making an equilibrium with those weights, is therefore equal to the product of those weights into the ratio of the sum of the radii of the pulley and the cord, to the radius of the axis, which ratio is very nearly 7 to 1, when the weight is suspended by a thin packthread, and nearly 7·2 to 1, when it is suspended by the cord No. 1. From these considerations the 9th column was calculated. The weights comprised in the 8th column are composed, 1. Of the weight of the pulley or cylinder; 2. Double the corresponding weight in the 5th column; 3. The weights contained in the 6th column; for the sum of these evidently compose the pressure upon the axis. Hence, to find the ratio of the friction to the pressure, as expressed in the 10th column, it is only to divide any number in the 9th column by the corresponding one in the 8th.

36. When it is proper to have regard to the velocity of the weight, to ascertain the effort which surmounts the friction and the stiffness of the cord, we may observe at once that in this case the motion is nearly a uniformly accelerated motion, since the first 3 feet are described in a time about double that employed in running over the last 3 feet. It remains, therefore, to learn what part w of the additional weight stated in the 6th column, which we call w, was employed in accelerating the motion of the suspended weight; for the other part of the additional weight, viz. $w - w'$, is manifestly that which surmounts the friction and the stiffness of the cords. Now t being the time of the whole descent, the accelerating force which has place is equal to $\frac{2 \times 6}{t^2}$; and, naming W the total sum of the weight hanging upon the pulley comprising in it 7 pounds for the inertia of the pulley, which weighed 14 pounds, and g the accelerating force of gravity, the mass put in motion will be $\frac{W}{g}$, and the product of that mass by the accelerating force will be $\frac{2 \times 6W}{gt^2}$; which being subtracted from the additional weight which put the pulley in motion, gives

the quantity $w-w'$, or the part of the weight w employed to overcome the stiffness of the cord and the friction.

It appears from the 7th, 8th, 9th, 10th, 11th, and 12th experiments, that the friction of axes of iron in boxes or cheeks of copper is much less softened by the cart-grease than by tallow.

37. M. Coulomb has likewise endeavoured to ascertain the friction of axes of rotation made of the different kinds of wood which are commonly found in rotatory machines. To render the friction more sensible he used pulleys of 12 inches mounted upon axes of 3 inches; sometimes the axes were immoveable, at others they moved, but in both cases the friction was the same: the proper precautions were adopted to smoothen the surfaces in contact, and thence to avoid the uncertainty and irregularity which might otherwise have attended the results.

Kinds of wood used in the experiments.	Ratio of friction to pressure.
Axis of holm-oak, box of lignum vitæ, coated with tallow	0·038
Ditto the coating wiped, the surface remaining oily	0·06
Axis and box as before, but used several times without having the coating refreshed	0·06 0·08
Axis of holm-oak, box of elm, coated with tallow	0·03
Ditto both axis and box wiped, surfaces remaining oily	0·05
Axis of box-tree, box of lignum vitæ, coated with tallow	0·043
Ditto the coating wiped, the surfaces remaining oily	0·07
Axis of box-tree, box of elm	0·035
Ditto the coating wiped off	0·05
Axis of iron, box of lignum vitæ, the coating wiped off and the pulley turned for some time	0·05

The velocity does not appear to influence the friction in any sensible manner, except in the first instants of motion: and in every case the friction is least, not when the surfaces are plastered over, but when they are merely oily.

38. The experiments on the stiffness of cords described (art. 34.) were made in cases of motions nearly insensible; but M. Coulomb inquired whether with a finite velocity the resulting effect of the stiffness of the cord were augmented or diminished. For this purpose he took a pulley and box of copper, and an axis of iron done over with tallow: the diameter of the pulley was 144 lines, and that of the axis $20\frac{1}{2}$ lines; and the cord was one of 30 threads to a yarn, or No. 3. of which the stiffness with respect to insensible velocities was determined by some of the foregoing experiments. The ensuing table shows the results of the experiments: the weights were made to run over a distance of 6 feet, and the times of describing the first three and the last three feet were measured by a half-second pendulum.

No. of experiments.	Weight hung on each side the pulley.	Additional weight to move the pulley.	Part of weight to overcome friction and rigidity.	Motion of the weights hung upon the pulley.	Pressure on the axis in lbs.	Weight acting at extremity of pulley, balancing the friction.	Stiffness of the cord deduced from the weights which move the pulley.	Stiffness of the cord estimated from its tension and former experiments
1	100lbs.	7·5lbs.	7·5 lbs.	Slow and continued.	221 lbs.	2·6 lbs.	4·9 lbs.	4·0 lbs.
		12	7·6	first 3 feet in 3″; last 3 feet in 1½″				
		15	7·6	first 3 feet in 2″; last 3 in 1½″				
2	200	11	11	Slow and uncertain.	425	4·9	6·1	6·6
		15	12·9	first 3 feet in 6″; last 3 in 3″				
		19	12·2	first 3 feet in 3½″; last 3 in 1½″				
3	400	20·5	20·5	Slow and uncertain.	834	9·7	10·8	11·8
		24	19·9	first 3 feet in 6″; last 3 in 3″				
		31	17·6	first 3 feet in 3″; last 3 in 2″				
4	600	31·5	31·5	Doubtful and continued.	1235	14·5	17·0	17·0
		37	31·5	first 3 feet in 6″; last 3 in 3½″				

It appeared in the table (art. 34.) that to bend the cord No. 3. of 30 threads in a yarn, about a roller of 12 inches diameter, and with a tension of 500 lbs. would require a weight of 14·4 lbs.: of which weight the constant part due to the fabrication of the cord is about 1·4 lbs: this value may be retained, but it will be here proper to reduce the part due to the tension of the cord by the quintal to $\frac{1}{5}(14\cdot4-1\cdot4)=\frac{1}{5}\times13=2\cdot6$ lbs. From these data the last column to the right of the above table was computed.

39. To complete the object of the experiments it is necessary to have the stiffness of the cord without asserting any thing *à priori* on the values which had been previously found for such rigidity. To this end Coulomb has estimated the friction of the axis from its charge and the experiments of art. 35; where it appeared that this friction was independent of its velocity and equal to 0·087 of the pressure. This friction which is exerted at the surface of the axis being computed, and the radius of the axis being to the distance between the centre of rotation and the middle of the cord as 1 to 7·5, it will be easy to calculate the weight which acting in the vertical direction of the middle of the cord may be in equilibrium with the friction in each experiment; and these weights are contained in the 7th column. Subtracting these weights from the additional weights contained

in the 3d column, namely those which put the pulley in motion, we have in the case of a very slow motion the values of the weights which just surmount the stiffness of the cord; these weights are comprised in the 8th column, and differ but little from those calculated immediately and contained in the 9th column.

40. Now to know if the greater or less velocity of the weight suspended upon the pulley has any influence upon the resistance due to the stiffness of the cord, we must in the case of the motion calculate what portion of the additional weight hung upon the pulley is employed in overcoming the friction and the rigidity of the cord. Here the formula of a preceding article has its application, $w' = \frac{2 \times 6w}{gt^2}$: for, the time occupied by the weight in describing the last three feet being nearly the half of that employed in describing the first three feet, the motion may be considered as uniformly accelerated, and the quantities $w - w'$ which result, and are contained in the 4th column, differ but little, as is manifest, from the weights employed to overcome the friction and the stiffness of the cords, in the case of an extremely slow motion. And as it appeared from the preceding experiments that the friction was independent of the velocity, or that it opposed the same resistance to the motion in the different trials for each experiment; it hence follows that the resistance arising from the stiffness of the cord was likewise constant in the same trials, and *depended not upon the velocity, at least in any such sensible manner as to merit our regard in computing the powers of machines.*

41. The invariableness of the resistance occasioned by the stiffness of cords, under different velocities, appears also immediately from the results comprised in the 5th column of the table, which, as before observed, proves that the motions were nearly uniformly accelerated. And from this property it follows, that there is always a constant part of the weight or power employed in surmounting the friction and stiffness of the cords.

"Nevertheless," adds M. Coulomb, "it must be acknowledged, that it is not *strictly* true, that the augmentation of velocity does not augment the resistance due to the rigidity of cordage. This augmentation appears especially perceptible when the cords are stretched with weights or by forces that are under 100 pounds. I have estimated, by many trials, that in such cases a velocity of 8 feet per second would increase by nearly a pound the resistance occasioned by the stiffness of our cord of 30 threads in a yarn: but this augmentation of resistance seems to be a constant quantity for the same degree of

velocity, whatever the tension may be: in such sort that it ceases to be perceptible under great tensions, and that there are but very few circumstances in which it may not be neglected in practice: this augmentation with regard to the velocity appears, besides, much greater in new than in old cords, and in tarred cords than in those which are white or untarred."

42. M. Coulomb deduces from these experiments the following general conclusions:

(1.) That with respect to practice, in all rotatory machines the ratio of the pressure to the friction may always be supposed constant, and that the influence of the velocity is too small to need our regard.

(2.) That the resistance which must be overcome to bend a cord over a roller or pulley is represented by a formula composed of two terms; the first is a constant quantity independent of the tension, and of the form $\frac{ad^n}{r}$ (art. 31.) where a is a constant quantity determined by experience, d^n is a power of the diameter d of the cord, and r the radius of the roller; the second term is $\frac{bd^n}{r}$ Q, where b is a constant quantity, d, n, and r, as before, and Q the tension of the cord. Thus the complete formula expressing the stiffness of the cord is $\frac{d^n}{r}(a + b\text{Q})$. The power n varies according to the flexibility of the cord, but is usually about 1·7 or 1·8, or the resistance is *nearly* proportional to the square of the diameter of the cord: when the cord is much used n decreases to 1·5 or even 1·4. The following is a summary of results.

			lbs.
White Cord,	of 30 threads in a yarn	$\frac{d^n}{r}a = 4{\cdot}2$	$\frac{d^n}{r}b.100 = 9{\cdot}0$
	—15	$= 1.2$	$= 5{\cdot}1$
	— 6	$= 0{\cdot}2$	$= 2{\cdot}2$
Tarred Cord,	of 30 threads in a yarn	$= 6{\cdot}6$	$= 11{\cdot}6$
	—15	$= 2{\cdot}0$	$= 5{\cdot}6$
	— 6	$= 0{\cdot}4$	$= 2{\cdot}4$

43. Our knowledge of the nature of the friction of axes, and stiffness of cords, though confessedly very imperfect, may be introduced into the computation of the power of machines: this may be illustrated by an example of a capstan or windlass, where the general formula of an equilibrium will be this:

$$\text{PR} = \text{QR}' + \frac{r\text{Q}}{\sqrt{\left(1 + \frac{1}{ff}\right)}} + d^n(a + b\text{Q})$$

where P represents the power, and the other letters as below.

The weight to be elevated is

$$Q = 1000 \text{ lbs.}$$

The radius of the axis or pivot, which is of iron, is

$$r = 2 \text{ inches.}$$

This axis turns in a box of copper: the radius of the cylinder about which the cord is rolled is

$$R' = 10 \text{ inches.}$$

The arm of the capstan, or the radius, or distance at which the men exert their force, is

$$R = 10 \text{ feet} = 120 \text{ inches.}$$

The pivots are supposed to have been plastered with tallow some time, and the instrument often used, till the ratio of the friction to the pressure is reduced to that of experiment 15. in the table of article 35. whence we have that ratio, or

$$f = 0{\cdot}133, \text{ and } \sqrt{(1+\frac{1}{ff})} = 7{\cdot}5851.$$

The cord is supposed tarred, and of 120 threads in a yarn, which will support 12 or 14000 lbs. without breaking. Now a tarred cord of 30 threads in a yarn requires a constant effort equivalent to 6·6 lbs. to bend it about a roller of 2 inches radius, and an effort proportional to the tension, of 11·6 lbs. for a quintal, or 116 lbs. for 1000 lbs. Here the radius of the cylinder being 10 inches, we must, first supposing the cords equal, diminish these efforts in the ratio of 10 to 2, viz. make their sum $= \frac{2}{10}(6{\cdot}6 + 116)$ for 1000 lbs., and $= \frac{2}{10}(6{\cdot}6 + \overline{8 \times 116})$ for 8000. And as the cord is of 120 threads in a yarn instead of 30, we must increase the last result, in the ratio of 30 to 120, so shall we have $\frac{4}{1} \times \frac{1}{5}(6{\cdot}6 + 928) = 747{\cdot}7$ for the effort which will surmount the stiffness of the cord, that is

$$\frac{d^n}{R'}(a + bQ) = 747{\cdot}7.$$

And since $R' = 10$, we have $d^n(a + bQ) = 7477$.
These values being substituted in the general formula it becomes

$$P \times 120 = (8000 \times 10) + \frac{8000 \times 2}{7{\cdot}5851} + 7477.$$

$$\text{or, } P = 666{\cdot}6 + 17{\cdot}577 + 62{\cdot}3 = 746{\cdot}5 \text{ lbs.}$$

It will be necessary therefore to distribute at the extremities of the bars of the capstan efforts whose sum shall be equivalent to 746·5 lbs.: that is, if a man makes an effort balancing 25 lbs., 30 men will be required to move the weight of 8000 lbs. Had there been no friction, and were the cords perfectly flexible, the force necessary would have been only $\frac{8000}{12}$ or 666·6, less than the other by almost 80 pounds, a difference which is more than equivalent to the force of three men. So that in this example

the friction and rigidity of the cord require an increase of between an 8th and a 9th of the whole power which would otherwise have been requisite.

This, however, we wish to be received only as an approximation. The details which have been here entered into will, we trust, be found of some utility in directing the practice, and may furnish some hints to those who have time and inclination to adopt other series of well-conducted experiments; and thus supply these most important desiderata in practical mechanics.

ON THE ENERGY OF FIRST MOVERS.

44. The consideration of the absolute and relative forces of different kinds of first movers is of too great consequence in the application of mechanics to be entirely omitted in this performance: we shall, therefore, present the reader with some observations and tables respecting the chief classes of powers used to drive machinery, viz. water, air, steam, gunpowder, and animal exertion.

Water is generally made to operate upon machines by means of its momentum when in motion: but it may also be used, and that as a very powerful mover, when acting by its pressure merely. In the theory of hydrostatics (art. 387.) we explained the principle of the hydrostatical paradox, in which it is asserted that any quantity of water or other fluid may be made to support any other quantity or any weight, however great, and indeed to *raise* the greater weight until it reaches such a height as ensures the equilibrium. Thus in the hydrostatic bellows the weight of a few ounces of water is made to raise several hundred pounds. And in like manner Otto Guericke of Magdeburg made a child balance, and even overcome, the pull exerted by the emperor's six coach horses, merely by sucking the air from beneath a piston. This great power depends upon the fundamental property of fluids, that *they press equally in all directions*. The late Mr. Bramah obtained a patent for a machine acting as a press on this principle of the *quaqua versum* pressure of fluids: A piston of $\frac{1}{4}$ of an inch diameter forces water into a cylinder of 12 inches diameter, and by this intervention raises the piston of the cylinder: so that a boy acting with a fourth part of his strength on the small piston, by means of a lever, can raise about 94080 lbs. or 42 tons pressing on the great piston; the increase of power being as 1 to $4^2 \times 12^2$ or 1 to 2304. This contrivance will be more minutely explained under the article Braham's *machine*, in the alphabetical part of this volume; its applications are numerous and highly important.

45. As to the effect of water in motion, it will manifestly depend upon the quantity of fluid and its velocity jointly. When the water runs through a notch or an orifice of a regular form situated in the bottom or side of a reservoir, the quantity discharged in any given time may be determined by the rules laid down for those purposes in Vol. I. Book IV. If s^2 be the area of any plane exposed to the action of a current of water, and v the velocity per second with which the fluid strikes the plane, then will the force of the fluid be equivalent to the weight of a volume of water expressed by $\frac{v^2 s^2}{2g}$, where g represents $32\frac{1}{6}$ feet, on the supposition that the water strikes the plane *directly*: but if the fluid strike the plane obliquely and I represent the angle of incidence, the force will be equivalent to the weight of the column $\frac{v^2 s^2}{2g} \sin^2 \mathrm{I}$. Or, since a cubic foot of water weighs $62\frac{1}{2}$ lbs. averd., if v and s be expressed in feet, we shall have $\frac{62\frac{1}{2} v^2 s^2}{2g} \sin^2 \mathrm{I} = \cdot 971502 \sin^2 \mathrm{I}\, v^2 s^2$ lbs. averd. for the equivalent weight, which becomes barely $\cdot 971502\, v^2 s^2$ lbs. when the plane is directly opposed to the fluid. See also art. 467. vol. i.

46. In the determination of the velocity of the stream it will be necessary either to ascertain the height h through which the water has fallen freely, as from the end of a spout, when $\sqrt{(2gh,)}$ or nearly $8\sqrt{h}$, will shew the velocity, h being in feet; or when the water issues through an orifice in the bottom or side of a reservoir, to have recourse to Chap. 1 and 2. Book IV. vol. I. before referred to. If the stream be ample without much fall, such as must necessarily be applied to move an undershot wheel by its impulse, the power will be determinable from the velocity of the water and the quantity which passes through the section of its bed. Dr. Desaguliers, in his Experimental Philosophy, vol. II. pa. 419. gives the following easy method of ascertaining these data: Observe a place where the banks of the river are steep and nearly parallel, so as to make a kind of trough for the water to run through, and, by taking the depth at various places in crossing, make a true section of the river. Stretch a string at right angles over it, and at a small distance another parallel to the first. Then take an apple, an orange, or other small ball, just so much lighter than water as to swim in it, and throw it into the water above the strings. Observe when it comes under the first string, by means of a half second pendulum, a stop-watch, or any other proper instrument; and observe likewise when it arrives at the second string. By these means the velocity of the upper surface, which in practice may *generally* be taken for that of the whole, will be obtained. And

the section of the river at the second string must be ascertained by taking various depths, as before. If this section be the same as the former, it may be taken for the mean section: if not, add both together, and take half the sum for the mean section. Then the area of the mean section in square feet being multiplied by the distance between the strings in feet, will give the contents of the water in solid feet, which passed from one string to the other during the time of observation; and this by the rule of three may be adapted to any other portion of time. Suppose, for example, the time were 12″, and the hourly expenditure of water were required, the proportion would be, as 12″ : 3600″ : : the number of cubit feet between the two strings : the hourly expenditure in cubit feet. If the mere velocity be required with reference to any fixed interval of time, a similar proportion will give it, only observing to take, instead of the solid content or capacity in the third term, the distance between the two strings.

The operation may often be greatly abridged by taking notice of the arrival of the floating body opposite two stations on the shore, especially when it is not convenient to stretch a string across. An arch of a bridge is a good station for an experiment of this kind, because it affords a very regular section and two fixed points of observation: and in some instances the sea practice of heaving the log may be advantageous. Where a time-piece is not at hand, the observer may easily construct a half-seconds or quarter-seconds pendulum: the former may be made by suspending a small round (not flat) button, or other spherical weight, by a thread looped over a pin of such a length that the distance from the point of suspension to the centre of the weight shall be 9·8 inches: the quarter-seconds pendulum must be a fourth of this length. If, by observations at several stations above and below any particular point of the river, the velocity does not appear to vary, the section of the river in all that space may be considered as uniform; and it will not be necessary to determine more than one section by actual measurement. See also the article *Stream-measurers* in this volume.

47. The effect of undershot and overshot wheels has been very variously stated by different authors; the most valuable and correct observations are those of Mr. Smeaton, an abstract of which was given in Chap. 4. Book IV. vol. I. The numerous practical remarks and experiments related in that chapter and the second chapter of the same book, will render it unnecessary for us now to dwell longer upon the effects of water as a mover of machinery.

48. Air is the next natural mover we propose to consider. And this, like water, may be regarded either as at rest, or in

motion. The pressure of the atmosphere in a medium state is equivalent to the weight of $14\frac{3}{4}$ or 15 lbs. averdupois on a square inch, and this pressure will support, and, by means of a sucking pump, *raise* water to the height of about 33 feet; it supports mercury in the barometer at the height of 28 to 32 inches. In many modern machines the pressure of the atmosphere furnishes the moving power.

The density of air is, at a medium, about 833 times less than that of water: if we take round numbers and reckon 800 to 1 for the ratio of the densities, and put s^2 for the surface on which the wind strikes, v for the velocity with which it moves, and I for the angle of incidence, then the force of the wind will be equal to the weight of a volume of water expressed by $\frac{1}{800}$.
$\frac{v^2 s^2}{2g} \sin {}^2\text{I} = \cdot 0012144\, v^2 s^2 \sin {}^2\text{I}$ lbs. averdupois.

This formula, however, is only an approximation, and would lead to considerable errors when the velocities are great: on this subject we have treated pretty fully in art. 554, &c. Book V. vol. I., where the tables of Dr. Hutton, Mr. Rouse, &c. are exhibited: the following is Mr. Rouse's table of velocity and corresponding force in the form it was originally given by Mr. Smeaton; and is inserted here, because it facilitates the comparison of velocities expressed in miles and feet.

Velocity of the Wind.		Perpendicular force on one square foot, in averdupois pounds.
Miles in one hour.	= feet in one second.	
1	1·47	·005
2	2·93	·020
3	4·40	·044
4	5·87	·079
5	7·33	·123
10	14·67	·492
15	22·00	1·107
20	29·34	1·968
25	36·67	3·075
30	44·01	4·429
35	51·34	6·027
40	58·68	7·873
45	66·01	9·963
50	73·35	12·300
60	88·02	17·715
80	117·36	31·490
100	146·70	49·200

49. As it is not easy to observe the true velocity of the wind, and thence determine its force, several philosophers have invented instruments called Anemometers or wind gages, by

which the *force* of the wind may be ascertained independent of its velocity. M. Bouguer contrived a very simple instrument for this purpose: it is a hollow tube AABB (fig. 5. pl. I.) in which a spiral spring CD is fixed, that may be more or less compressed by a rod FSD passing through a hole within the tube at AA. Having observed to what degree different forces or given weights are capable of compressing the spiral, put divisions upon the rod in such a manner that the mark observed at S in all positions of that rod shall indicate the weight requisite to force the spring into the corresponding position CD. Afterwards join perpendicularly to this rod at F a plane surface EFE of a given area, either greater or less, as may be judged proper: then nothing more is necessary than to oppose this instrument to the wind, in order that it may strike the surface in the directions VE, VE, parallel to that of the rod; and the mark at S will shew the weight to which the wind is equivalent. It will then be easy to reduce any observed force to a volume of water equivalent to it in energy; and so in all cases ascertain the magnitude of the force which the wind exerts.

50. The most usual method of applying wind as a mover of machinery is in the construction of windmills for different purposes, in which the wind produces its effect by impulse upon the sails. In these machines, therefore, whatever varieties there may be in the internal structure, there are certain rules with regard to the position, shape, and magnitude of the sails, which will bring them into the best state for the action of the wind, and the production of useful effect. These particulars have been considered much at large by Mr. Smeaton: for this purpose he constructed a machine of which a particular description is given in the Philosophical Transactions, vol. 51. or in the quarto collection of his "Miscellaneous Papers," p. 55. By means of a determinate weight it carried round an axis with an horizontal arm, upon which were four small moveable sails. Thus the sails met with a constant and equable blast of air; and as they moved round, a string with a weight affixed to it was wound about their axis, and thus showed what kind of size or construction of sails answered the purpose best. With this machine a great number of experiments were made; the results of which are as follow:

(1.) The sails set at the angle with the axis, proposed as the best by M. Parent and others, *viz.* 55°, was found to be the worst of any that was tried.

(2.) When the angle of the sails with the axis was increased from 72° to 75°, the power was augmented in the proportion of 31 to 45; and this is the angle most commonly in use when the sails are planes. See art. 547. vol. I.

(3.) Were nothing more requisite than to cause the sails to acquire a certain degree of velocity by the wind, the position recommended by M. Parent would be the best. But if the sails are intended with given dimensions to produce the greatest effects possible in a given time, we must, if planes are made use of, confine our angle within the limits of 72 and 75 degrees.

(4.) The variation of a degree or two, when the angle is near the best, is but of little consequence.

(5.) When the wind falls upon concave sails it is an advantage to the power of the whole, though each part separately taken should not be disposed of to the best advantage.

(6.) From several experiments on a large scale, Mr. Smeaton has found the following angles to answer as well as any. The radius is supposed to be divided into six parts; and $\frac{1}{6}$th, reckoning from the centre, is called 1, the extremity being denoted 6.

No.	Angle with that axis.	Angle with the plane of motion.
1	72°	18°
2	71	19
3	72	18 middle.
4	74	16
5	$77\frac{1}{2}$	$12\frac{1}{2}$
6	83	7 extremity.

(7.) Having thus obtained the best method of *weathering* the sails, *i. e.* the most advantageous manner in which they can be placed, our author's next care was to try what advantage could be derived from an increase of surface upon the same radius. The result was, that a broader sail requires a larger angle; and when the sail is broader at the extremity than near the centre, the figure is more advantageous than that of a parallelogram. The figure and proportion of enlarged sails, which our author determines to be most advantageous on a large scale, is that where the extreme bar is one-third of the radius or whip (as the workmen call it), and is divided by the whip in the proportion of 3 to 5. The triangular or loading sail is covered with board from the point downward of its height, the rest as usual with cloth. The angles above-mentioned are likewise the most proper for enlarged sails; it being found in practice, that the sails should rather be too little than too much exposed to the direct action of the wind.

Some have imagined, that the more sail the greater would be the power of the windmill, and have therefore proposed to fill up the whole area; and by making each sail a sector of an el-

lipsis, according to M. Parent's method, to intercept the whole cylinder of wind, in order to produce the greatest effect possible. From our author's experiments, however, it appeared, that when the surface of all the sails exceeded seven-eighths of the area, the effect was rather diminished than augmented. Hence he concludes, that when the whole cylinder of wind is intercepted, it cannot then produce the greatest effect, for want of proper interstices to escape.

"It is certainly desirable (says Mr. Smeaton,) that the sails of windmills should be as short as possible; but it is equally desirable, that the quantity of cloth should be the least that may be, to avoid damage by sudden squalls of wind. The best structure, therefore, for large mills, is that where the quantity of cloth is the greatest in a given circle that can be: on this condition, that the effect holds out in proportion to the quantity of cloth; for otherwise the effect can be augmented in a given degree by a lesser increase of cloth upon a larger radius than would be required if the cloth was increased upon the same radius."

(8.) The ratios between the velocities of windmill sails unloaded, and when loaded to their maximum, turned out very different in different experiments; but the most common proportion was as 3 to 2. In general it happened that where the power was greatest, whether by an enlargement of the surface of the sails or an increased velocity of the wind, the second term of the ratio was diminished.

(9.) The ratios between the least load that would stop the sails and the maximum with which they would turn, were confined betwixt that of 10 to 8 and 10 to 9; being at a medium about 10 to 8·3, and 10 to 9, or about 6 to 5; though on the whole it appeared, that where the angle of the sails or quantity of cloth was greatest, the second term of the ratio was less.

(10.) The velocity of windmill sails, whether unloaded or loaded, so as to produce a maximum, is nearly as the velocity of the wind, their shape and position being the same. On this subject Mr. Ferguson remarks, that it is almost incredible to think with what velocity the tips of the sails move when acted upon by a moderate wind. He has several times counted the number of revolutions made by the sails in 10 or 15 minutes; and, from the length of the arms from tip to tip, has computed, that if a hoop of the same size were to run upon plain ground with an equal velocity, it would go upwards of 30 miles in an hour.

(11.) The load at the maximum is nearly, but somewhat less than, as the square of the velocity of the wind; the shape and position of the sails being the same.

(12.) The effects of the same sails at a maximum are nearly, but somewhat less than, as the cubes of the velocity of the wind.

(13.) The load of the same sails at a maximum is nearly as the squares, and the effect as the cubes of their number of turns in a given time.

(14.) When sails are loaded so as to produce a maximum at a given velocity, and the velocity of the wind increases, the load continuing the same; then the increase of effect, when the increase of the velocity of the wind is small, will be nearly as the squares of these velocities: but when the velocity of the wind is double, the effects will be nearly as 10 to $27\frac{1}{2}$; and when the velocities compared are more than double of that where the given load produces a maximum, the effects increase nearly in a simple ratio of the velocity of the wind. Hence our author concludes, that windmills, such as the different species for draining water, &c. lose much of their effect by acting against one invariable opposition.

(15.) In sails of a similar figure and position, the number of turns in a given time will be reciprocally as the radius or length of the sail.

(16.) The load at a maximum that sails of a similar figure and position will overcome, at a given distance from the centre of motion, will be as the cube of the radius.

(17.) The effects of sails of similar position and figure are as the square of the radius. Hence augmenting the length of the sail without augmenting the quantity of cloth, does not increase the power; because what is gained by length of the lever is lost by the slowness of the motion. Hence also, if the sails are increased in length, the breadth remaining the same, the effect will be as the radius.

(18.) The velocity of the extremities of the Dutch sails, as well as of the enlarged sails, either unloaded or even when loaded to a maximum, is considerably greater than that of the wind itself. This appears plainly from the observations of Mr. Ferguson, already related, concerning the velocity of sails.

(19.) From many observations of the comparative effects of sails of various kinds, Mr. Smeaton concludes, that the enlarged sails are superior to those of the Dutch construction.

(20.) He also makes several just remarks upon those windmills which are acted upon by the direct impulse of the wind against sails fixed to a vertical shaft: his objections have, we believe, been justified in every instance by the inferior efficacy of these horizontal mills.

"The disadvantage of horizontal windmills (says he) does not consist in this, that each sail, when directly opposed to the

wind, is capable of a less power than an oblique one of the same dimensions; but that in a horizontal windmill little more than one sail can be acting at once; whereas, in the common windmill, all the four act together; and therefore, supposing each vane of a horizontal windmill to be of the same size with that of a vertical one, it is manifest that the power of a vertical mill will be four times as great as that of a horizontal one, let the number of vanes be what they will. This disadvantage arises from the nature of the thing; but if we consider the further disadvantage that arises from the difficulty of getting the sails back again against the winds, &c. we need not wonder if this kind of mill is in reality found to have not above one-eighth or one-tenth of the power of the common sort; as has appeared in some attempts of this kind."

51. Another first mover, of whose effects it may be proper to give some account, is *fired gunpowder*. These effects are too violent and sudden to allow of their being applied to many practical purposes (the chief use of gunpowder being in the discharge of balls and shells from guns and mortars;) but they are so prodigious and extraordinary, and are so important in the art of war, that it may be naturally expected we should give some estimate of them in this place.

Now, to understand the force of gunpowder, it must be considered that whether it be fired in a vacuum or in air, it produces by its explosion a permanently elastic fluid: and it appears from experiment that the elasticity or pressure of the fluid produced by this firing of gunpowder is, *cæteris paribus*, directly as its density.

To determine the elasticity and quantity of this fluid produced from the explosion of a given quantity of gunpowder, Mr. Robins premises, that the elasticity increases by heat, and diminishes by cold, in the same manner as that of the air; and that the density of this fluid, and consequently its weight, is the same with the weight of an equal bulk of air, having the same elasticity and the same temperature. From these principles, and from the experiments by which they are established (for a detail of which we must refer to the book itself,) he concludes that the fluid produced by the firing of gunpowder is nearly $\frac{3}{10}$ of the weight of the generating powder itself; and that the volume or bulk of this air or fluid, when expanded to the rarity of common atmospheric air, is about 244 times the bulk of the said generating powder.—Count Saluce, in his Miscel. Phil. Mathem. Soc. Priv. Taurin. p. 125, makes the proportion as 222 to 1; which he says agrees with the computation of Messrs. Hauksbee, Amontons, and Belidor.

Hence it would follow that any quantity of powder fired in

any confined space, which it adequately fills, exerts at the instant of its explosion against the sides of the vessel containing it, and the bodies it impels before it, a force at least 244 times greater than the elasticity of common air, or, which is the same thing, than the pressure of the atmosphere; and this without considering the great addition arising from the violent degree of heat with which it is endued at that time; the quantity of which augmentation is the next head of Mr. Robins's enquiry. He determines that the elasticity of the air is augmented in a proportion somewhat greater than that of 4 to 1, when heated to the extremest heat of red-hot iron; and supposing that the flame of fired gunpowder is not of a less degree of heat, increasing the former number a little more than 4 times, makes nearly 1000; which shows that the elasticity of the flame, at the moment of explosion, is about 1000 times stronger than the elasticity of common air, or than the pressure of the atmosphere. But, from the height of the barometer, it is known that the pressure of the atmosphere upon every square inch is on a medium $14\frac{3}{4}$ lb.; and therefore 1000 times this, or 14750 lb. is the force or pressure of the flame of gunpowder, at the moment of explosion, upon a square inch, which is very nearly equivalent to 6 tons and a half.

This great force, however, diminishes as the fluid dilates itself, and in that proportion, viz. in proportion to the space it occupies, it being only half the strength when it occupies a double space, one-third the strength when the triple space, and so on.

Mr. Robins further supposed the degree of heat above mentioned to be a kind of medium heat; but that in the case of large quantities of powder the heat will be higher, and in very small quantities lower; and that therefore in the former case the force will be somewhat more, and in the latter somewhat less, than 1000 times the force of the atmosphere.

He further found that the strength of powder is the same in all variations in the density of the atmosphere: but that the moisture of the air has a great effect upon it; for the same quantity which in a dry season would discharge a bullet with a velocity of 1700 feet in one second, will not in damp weather give it a velocity of more than 12 or 1300 feet in a second, or even less, if the powder be bad, and negligently kept. Robins's Tracts, vol. 1, p. 101, &c. Further, as there is a certain quantity of water which, when mixed with powder, will prevent its firing at all, it cannot be doubted but every degree of moisture must abate the violence of the explosion; and hence the effects of damp powder are not difficult to account for.

The velocity of expansion of the flame of gunpowder, when fired in a piece of artillery, without either bullet or other body

before it, is prodigiously great, viz. 7000 feet per second, or upwards, according to the experiments of Mr. Robins. But M. Bernoulli, and M. Euler think it is still much greater.

Dr. Hutton, after applying some requisite corrections to Mr. Robins's numbers, and after remarking that the powder does not all inflame at once, as well as that about $\frac{7}{10}$ of it consists of gross matter not convertible into an elastic fluid, gives $v = 125\sqrt{(\frac{nq}{16+q} \times \log. \text{ of } \frac{b}{a})}$ for the initial velocity of any ball of given weight and magnitude, and $n = \frac{p+w}{2180\,ad^2}\,v^2 \div \log. \frac{b}{a}$ for the value of the initial force n of the powder in atmospheric pressures: where $a =$ length of the bore occupied by the charge, $b =$ whole length of the bore, $d =$ diameter of the ball, $w =$ its weight, $2p =$ weight of the powder, $q = \frac{a}{d}$. In his experiments and results he found n to vary between 1700 and 2300; and the velocity of the flame to vary between 3000 and 4732; specifying, however, the modification in his computations which would give more than 7000 feet per second for that velocity. Taking 2200 for an average value of n, and substituting 47 for its square root in the above formula for v, it becomes $v = 5875\sqrt{(\frac{q}{16+q} \times \log. \text{ of } \frac{b}{a})}$ for the velocity of the ball, a theorem which agrees remarkably well with the doctor's numerous and valuable experiments; (*Tracts*, vol. iii. pp. 290—315.) though it falls a little short of the velocities observed in the years 1815—1818, in the experiments carried on by General Millar, Col. Griffiths and myself.

In a French work entitled "*Le Mouvement Igné*, considéré principalement dans la charge d'une Pièce d'Artillerie," published in 1809, there are advanced, among some notions which we apprehend few philosophers will be inclined to adopt, some which may demand and deserve a careful consideration. The author of this work observes that if a fluid draws its force, partly from a gaseous or aëriform matter, and partly from the action of caloric, which rarefies that aëriform matter; then its density in the process of dilatation, will follow the inverse ratio of the spaces described, and at the same time the intensity of the heat will follow the same ratio: so that the force of the totality of the fluid will conform to the inverse ratio of the squares of the spaces described. He then investigates two classes of formulæ: the first appertain to fluids which possess simply the fluid or aëriform elasticity, which are free from all heat exceeding the temperature of the atmosphere; whether there be one or many gaseous substances signifies not, provided their temperature

agrees with that of the atmosphere; for when these dilate they conform to the inverse ratio of the spaces described. The second relate to those which derive their elasticity as well from the aëriform fluids as from the matter of heat which pervades them, and which are denominated *fluids of mixt elasticity*, to distinguish them from those of simple or purely *aëriform elasticity:* these fluids, in dilating, conform to the inverse ratio of the *squares* of the spaces described. Thus the celerity of action of mixed elastic fluids, is to that of simple elastic fluids, as s^2 to s; whence it follows that mixed elastic fluids are more prompt and energetic in their action than others; and hence also is inferred why the fluid produced by the combustion of gunpowder is more impetuous and more terrible in its operation than atmospheric air, however compressed it may be. The force exerted by the caloric to dissolve a quantity of powder, is regarded as equal to that possessed by the fluid which results from that dissolution, and is named *force of dissolution* of powder by fire: and the *surface of least resistance*, is that (as of the ball) which yields to the action of the fluid. The gunpowder subjected to experiment by this author, was of seven different qualities, varying from 1000 the density of water, down to 946 the density of the powder used by sportsmen. It was found by theory, and confirmed by experiment, that the real velocity with which the elastic fluid considered under the volume of the powder, and penetrated by a degree of heat capable of quadrupling the volume, would expand when it had only the resistance of the atmosphere to surmount, is 2546·49 feet, that is, about 2734·4 feet English.

Comparing the several forces which were calculated for the same quantity of powder in three different circumstances:

1. When the fluid has only to surmount the atmospheric pressure, it has a force of dissolution which is proper to it, and which, in a charge of 8 lbs. of powder, specific gravity 944·72, for a 24-pounder, acts upon the surface of least resistance with an energy equivalent to 9747·8074 pounds.

2. The fluid, retarded in its expansion by a surface of least resistance, whose tenacity (occasioned by the compactness and pressure of the wadding, &c.) $T = 31$ pounds, acquires by its elasticity a force $= 52839·1463$ pounds, at the instant when that surface yields to its action.

3. If the tenacity $T = 298$ pounds, the force of the fluid at the moment when the resisting surface yields to it will be equivalent to 417371·4275 pounds.

If each of these forces be divided by the surface of least resistance, the quotient will indicate the force of each fluid filament, namely,

1. That of the force of dissolution = 173·63 grains.
2. When T = 31 lbs. that of elasticity = 923·26 grains.
3. When T = 298 lbs. force elastic = 7433·99 grains.

Dividing again these latter values by the length of the charges, we shall have for the mean force of each elementary fluid particle

1. Force of dissolution . . = 0·14205 grains.
2. When T = 31 lbs. force elastic = 0·75540 grains.
3. When T = 298 lbs. force elastic = 6·08174 grains.

It appears, however, that equal charges of powder of the same quality, employed in the same piece, produce very different velocities, the more considerable being the resistance to the expansion of the fluid, the less the velocity becomes. Thus, it is found that when T = 31 lbs. the velocity of the ball when expelled at the mouth of the piece is 1563·6 feet: when T = 298 lbs. V = 1350·9 feet.

The following table will exhibit in one view, the velocities with which a 24 pound ball issues from the mouth of a gun, when propelled with the several charges expressed in the first column. 1st. According to the theory developed in the volume from which we have made these extracts. 2dly. According to the experiments of M. Lombard at Auxerre, on guns for land service. 3dly. According to the experiments of M. Teixier de Norbec, at Toulon, on guns for sea service. 4thly and 5thly, According to the determinations of Mr. Robins and Dr. Hutton.

Charges of Powder.	Veloc. from Theory when T=31	when T=298	Mean velocity from theory.	Veloc. from Experim. Lombard.	Norbec.	Velocities. Robins.	Hutton.
1 lb.	622	524	573	575	570	640	500
2½	980	836	908	906	940	750	730
3	1072	918	995	989	1020	969	830
4	1233	1057	1145	1132	1245	1069	940
6	1407	1216	1312	1320	1340	1215	1164
8	1564	1351	1457	1425	1560	1319	1348
10	1581	1370	1476	1475			1500
12	1631	1421	1526	1530			1600

It is the prodigious celerity of expansion of the flame of fired gunpowder which is its peculiar excellence, and the circumstance in which it so eminently surpasses all other inventions, either ancient or modern: for as to the momentum of these projectiles only, many of the warlike machines of the ancients produced this in a degree far surpassing that of our heaviest cannon shot or shells; but the great celerity given to them cannot be approached with facility by any other means than the explosion of powder.

52. Since the important invention of the Steam-engine, another species of first movers has come under the consideration of the mechanical investigator, namely, such as arise from the volatilisation of different fluids. Of these the one most commonly chosen is the STEAM raised from hot water, which is an elastic fluid, and which when raised with the ordinary heat of boiling water is almost 3000 times rarer than water, or more than $3\frac{1}{2}$ times rarer than air, and then has its elasticity equal to that of the common atmospheric air: by great heat it has been found that the steam may be expanded into 14000 times the space of water, and then exerts a force of nearly 5 times the pressure of the atmosphere: and there is no reason to suppose this is the limit: indeed some accidents which have happened prove clearly that the elastic force of steam may at least equal that of gunpowder.

The observations on the different degrees of temperature acquired by water in boiling, under different pressures of the atmosphere, and the formation of the vapour from water under the receiver of an air-pump, when with the common temperatures the pressure is diminished to a certain degree, show clearly that the expansive force of vapour or steam is different in the different temperatures, and that in general it increases in a variable ratio as the temperature is raised. Previous to describing the method which has been adopted to measure the force of steam under different temperatures, it will be proper to describe briefly the method by which the Chemists account for the production of aëriform fluids.

53. The term *Caloric* is used to denote the cause, whatever it may be, of heat, and of the phenomena which accompany heat: it is now almost universally admitted to be a highly elastic fluid. Every body is, according to its nature, capable of containing under a given volume a certain quantity of caloric, either greater or less: this property was first observed by Dr. Black, and the English chemists designated it by the term *Capacity of a body to contain the matter of heat.* Professor Wilcke and M. Lavoisier first made use of the term *specific caloric*, denoting by it the quantity of caloric respectively necessary to elevate to the same number of degrees the temperature of several bodies of equal weight.

Substances volatilised and reduced to *gas*, or aëriform fluids, are nothing else than ordinary solid or fluid bodies which by some circumstance are found superabundantly combined with caloric, in such a manner that the constituent particles of these bodies are separated the one from the other, by a quantity of ambient caloric much more considerable than that which surrounds the same particles in the natural state of the bodies.

The extreme elasticity of the caloric the effect of which is augmented by its condensation, and the weakening of the reciprocal attraction or of the cohesion of the particles of the bodies (a weakening or diminution produced by the increased distance of those particles) concur to diminish the density of the bodies in such a manner that they become reduced to an aëriform state.

54. As to the elasticity of gaseous fluids thus formed, it appears in great measure to be produced by the elasticity of caloric itself, which, when bodies are reduced to the gaseous state, occupy a very great part of their volume. This eminent elasticity of caloric tends continually to produce expansion; on the other hand, this fluid, by a particular destination of nature, is more or less disseminated between the moleculæ of all bodies, in such sort that we may say with M. Lavoisier that even in the solid state these moleculæ do not touch, but, as it were, *swim* in the caloric at a certain distance from each other. There must, therefore, be a perpetual contest between the expansive force of caloric which tends to disseminate the moleculæ, and the cohesive attraction of the moleculæ which tends to join them together. From the reciprocal intensity of these two powers results the solid and liquid states of bodies: thus, water only differs from ice by the greater or less condensation of caloric, which permits more or less of the moleculæ of the liquid to yield to the effect of their attraction or reciprocal cohesion.

When substances pass from the liquid to the aëriform state, there is a third power to combine with the expansive effort of caloric, and the aggregate or attractive effort of the moleculæ; namely, the pressure of the atmosphere, or of any elastic fluid whatever which compresses the fluid, and opposes itself to the separation of its parts. This third power has a certain influence also upon the passage from the solid to the fluid state, but it is most frequently (in this case) very small, and even evanescent, in comparison of the resistance arising from the mutual cohesion of the moleculæ. The contrary effect has place in the course of the passage from the liquid to the gaseous or aëriform state; the cohesion of the fluid moleculæ being extremely small, the elasticity of the caloric has scarcely any thing to surmount to produce volatilisation besides the pressure of the atmosphere, or gas which actually compresses it.

55. Hence it results that the same liquid under different pressures ought to volatilise at different temperatures. M. Lavoisier proved the truth of this result, by placing ether under the receiver of an air-pump, and producing volatilisation solely by taking off a part of the pressure of the atmosphere. See *Chymie, tome I. pa.* 9. And we know by many experiments

of M. Deluc and others, that water boils the more speedily as it is less pressed by the weight of the atmosphere.

Lavoisier notices a curious consequence of what has been here said; which is, that if our planet revolved upon its axis with such a velocity as to lessen the pressure of the atmosphere, or if the temperature of the air were raised, then several fluids which we now see under a liquid state would only exist in the aëriform state; for example, if under the temperature of summer the pressure of the atmosphere were only equivalent to 20 or 24 inches of the barometrical tube, that pressure would not retain ether in the fluid state, it would be changed into gas; and the like would happen, if while the pressure of the air was equivalent to 28 or 30 inches of the mercury the habitual temperature were 105 or 110 degrees on Fahrenheit's scale.

56. The principles which have been here exhibited are sufficient for the understanding of all which relates to the action of water or other fluids reduced to vapour. Now it has appeared from frequent experiments that water heated in common air volatilises at 80° of Reaumur's thermometer, or 212° of Fahrenheit's, the height of the barometer being 28 French, or 29·9 English inches: and spirits of wine under a like pressure volatilises at between 63° and 64° of Reaumur, or nearly 175° of Fahrenheit. The expansive force of the vapour must, therefore, in both these cases, according to the principles just explained, be measured by a column of mercury of 28 French, or 29·9 English inches, in like manner as such a column measures the pressure of the atmosphere, or the elasticity of common air. And at any more elevated temperatures the elastic force of the vapour will surpass the pressure of the atmosphere by a quantity which has a certain relation with the excess of the temperature above those just stated.

57. Till lately there was wanting on this important subject a series of exact and direct experiments by means of which, having given the temperature of the heated fluid, the expansive force of the steam rising from it might be known, and *vice versâ*. There was likewise wanting an analytical theorem expressing the relation between the temperature of the heated fluid and the pressure with which the force of the steam was in equilibrio. These desiderata have, however, been lately supplied with all desirable success and accuracy.

58. The investigation was much simplified by the discovery of a singular property of vapours, namely, *that their density necessarily depends upon their temperature;* so that to every degree of temperature belongs a certain and determinate degree of density, which remains constant, whilst the space through which the vapour is diffused is diminished or increased. And

this happens, because, whilst the space occupied is diminished, a part of the vapour is condensed, and is turned into water; and whilst the space occupied is dilated, the subjacent water disengages a fresh supply of vapour; whence, upon the whole, the density suffers no change.

59. This constant density, however, of vapour only obtains, where there is a quantity of water, sufficient to furnish so much vapour as will fill the whole capacity of the space, through which the vapour is diffused, and will maintain it at the assigned degree of density. Otherwise, the density will necessarily decrease, and will go on decreasing more and more, the more the capacity of the recipient is enlarged: and, on the contrary, if this capacity be diminished, the density will go on increasing, until it reach the assigned degree; at which it will remain constant, however the space be afterwards diminished.

When vapour is employed as a mechanical agent, there is always a reservoir of water, capable of evolving new vapour sufficient to keep the recipient space full. Wherefore, we may safely suppose vapour to have that degree of density, which belongs to its temperature, and we may investigate how much its elastic force increases, whilst its temperature increases.

60. *Experiment.* This investigation was conducted with singular accuracy by Dalton, (*Manchester Mem.* 1805.) His apparatus consisted of a simple barometer-tube, of which the inner surface was wetted before the introduction of the mercury. The mercury, well freed from air, having been afterwards poured in, after the usual manner, the tube, having been inverted, and its mouth immersed in a vessel full of mercury, the moisture, introduced into the tube was collected in the vacuum at the top, and a thin layer of water stood upon the surface of the mercury. The temperature was then gradually increased, by pouring water, more and more heated, into a gun-barrel which surrounded the whole of the upper part of the tube. As the temperature increased, the column of mercury sunk more and more. The height of this column having been subtracted from the height which represents the pressure of the atmosphere, that is, from the height of the mercury in a common barometer, there resulted the measure of the elasticity of the vapour.

61. The column of mercury remaining at the height which corresponds to the degree of the temperature, experiments were made, of lowering the tube, by plunging its orifice to a greater depth in the subjacent vessel of mercury; and also of raising it; and it was found, in both cases, that the height of the column of mercury, above the level of that in the vessel, always remained the same. This is an evident proof, that the

elasticity of the vapour also remains the same, although the capacity of the space occupied by the vapour is diminished in the first case, and increased in the second: and it confirms the position that, at the same temperature, the density of the vapour remains constant.

62. The correspondence between the temperature of the vapour and its elastic force is as follows, exhibited in altitudes of the mercurial column.

Temperature. Cent.	Fahr.	Elasticity Metres.	Elasticity Inches.
0°	32°	0·005	0·1969
10	50	0·009	0·3543
20	68	0·017	0·6693
30	86	0·031	1·1541
40	104	0·053	2·0203
50	122	0.088	3·4646
60	140	0.145	5·7088
70	158	0·228	8·9766
80	176	0.352	13·8586
90	194	0·525	20.6698
100	212	0·760	29·99
110	230	*1·069	
120	248	*1·462	
130	266	*1·941	

It is to be remarked that, with Dalton's apparatus, the temperature could not be carried higher than that of boiling water: hence the elasticities, corresponding to temperatures greater than 100° cent. 212 Fahr., were not found from observation, but from calculations made upon the supposition that they go on according to the same law, as that which they follow in lower temperatures; which law we shall proceed to investigate.

63. The temperatures increasing in arithmetic progression, the elasticities increase nearly in geometric progression. And it will be found that, in fact, their logarithms increase with very nearly equal differences.

64. Bettancourt has, also, with great diligence, succeeded in investigating the elasticity of vapours. His apparatus consisted of a large vat or boiler, a determinate portion of which he filled with water; he then closed it hermetically, and exhausted the air; afterwards, applying fire below it, he gradually raised the temperature of the water, and of the vapour which is disengaged from it, and diffused through the vacuum of the boiler. A long barometer, in the form of a syphon, communicated with the interior of the boiler. In proportion as the vapour, more and more heated, acquired force, the level

of the mercury fell in the nearer branch of the syphon, and rose in the other branch. The difference of the levels measured the elasticity of the vapour, at the same time that a thermometer, with its bulb plunged in the boiler, and rising out of it with a long neck, indicated the corresponding temperature.

The results of Bettancourt's experiments, although they do not exactly coincide with those of the experiments of Dalton, are, however, sufficiently conformable to them. And thus the law of nature, which establishes a correspondence between the temperature and the elasticity of aqueous vapour, is fully ascertained, by two series of experiments, conducted according to different processes.

Since the elasticity increases much faster than the temperature, we see plainly that, in very high temperatures, the force of vapour may become surprisingly great; and thus the prodigious effects which are related of it become accounted for.

65. Mr. Dalton's first experiments with spirit of wine led him to adopt the same conclusion as M. Bettancourt, with respect to the constant ratio between the force of the vapour from this spirit and that from water; and inferred the same with regard to the vapour from other fluids. But, on pursuing the subject, he concluded that this principle was not true, either with respect to spirit of wine or any other liquid. His experiments upon six different liquids agree in establishing as a general law, "*That the variation of the force of vapour from* "*all liquids is the same for the same variation of temperature,* "*reckoning from vapour of any given force.*"

If x denote the degrees of heat measured on Fahrenheit's thermometer from 212°, the ordinary boiling point of water, and f be the force of compression measured in inches of mercury, then, to express the elasticity of the steam generated from water, we have this logarithmic formula: viz.

$$\text{Log. } f = \log. 30 + \frac{4x}{45} \log. \left(1{\cdot}250 - {\cdot}015 \cdot \frac{4x}{45}\right).$$

Hence when x is known, we may find f, which measures both the compression on the surface of the water, and the elastic force of the steam. The above theorem will serve to estimate the force of steam generated from any other liquid, provided it be reckoned from the ordinary boiling point of the respective liquid, when the barometer stands at 30 inches.

66. There remains for us to consider another kind of mover of machinery, which is Animal Exertion, and which is of so fluctuating a nature that it is not easy to subject it to any estimate. Physical causes must affect both the magnitude and duration of the efforts either of man or beast, and besides this, the strength of man is considerably influenced by his moral

habits. The various combinations of these different causes have occasioned a variety of estimates of animal labour to be advanced by different authors.

In the first volume of this work (art. 378.) we stated the average force of a man at rest to be 70 lbs., and his utmost walking velocity when unloaded to be about 6 feet per second; and we thence inferred that a man would produce the greatest momentum when drawing $31\frac{1}{9}$ lbs. along a horizontal plane with a velocity of 2 feet per second. But this is not the most advantageous way of applying human strength.

67. Dr. Desaguliers asserts, that a man can raise of water or any other weight about 550 lbs., or one hogshead (weight of the vessel included), 10 feet high in a minute; this statement, though he says it will hold good for 6 hours, appears from his own facts to be too high; and is certainly such as could not be continued one day after another. Mr. Smeaton considers this work as the effort of haste or distress; and reports that 6 good English labourers will be required to raise 21141 solid feet of sea water to the height of four feet in four hours: in this case the men will raise a very little more than 6 cubic feet of fresh water each to the height of 10 feet in a minute. Now the hogshead containing about $8\frac{1}{2}$ cubic feet, Smeaton's allowance of work proves less than that of Desaguliers in the ratio of 6 to $8\frac{1}{2}$ or 3 to $4\frac{1}{4}$. And as his good English labourers who can work at this rate are estimated by him to be equal to a double set of common men picked up at random, it seems proper to state that, with the probabilities of voluntary interruption, and other incidents, a man's work for several successive days ought not to be valued at more than half a hogshead raised 10 feet high in a minute. Smeaton likewise states that two ordinary horses will do the work in three hours and twenty minutes, which amounts to little more than two hogsheads and a half raised 10 feet high in a minute. So that, if these statements be accurate, one horse will do the work of five men.

Mr. Emerson affirms, that a man of ordinary strength turning a roller by the handle can act for a whole day against a resistance equal to 30 pounds weight; and if he works 10 hours a day he will raise a weight of 30 lbs. through $3\frac{1}{2}$ feet in a second of time; or, if the weight be greater, he will raise it to a proportionally less height. If two men work at a windlass or roller, they can more easily draw up 70 lbs. than one man can 30 lbs.; provided the elbow of one of the handles be at right angles to that of the other. Men used to bear loads, such as porters, will carry from 150 lbs. to 200 or 250 lbs. according to their strength. A man cannot well draw more than 70 lbs. or 80 lbs. horizontally: and he cannot thrust with a

F 2

greater force acting horizontally at the height of his shoulders than 27 or 30 lbs. But one of the most advantageous ways in which a man can exert his force is to sit and pull towards him nearly horizontally, as in the action of rowing.

M. Coulomb communicated to the French National Institute the results of various experiments on the quantity of action which men can afford by their daily work, according to the different manners in which they employ their strength. In the first place he examined the quantity of action which men can produce when, during a day, they mount a set of steps or stairs, either with or without a burthen. He found that the quantity of action of a man who mounts without a burthen, having only his own body to raise, is double that of a man loaded with a weight of 68 kilogrammes, or 150 lbs. avoirdupois *, both continuing at work for a day. Hence it appears how much, with equal fatigue and time, the total or absolute effort may obtain different values by varying the combinations of effort and velocity.

But the word *effect* here denotes the total quantity of labour employed to raise, not only the burthen, but the man himself; and, as Coulomb observes, what is of the greatest importance to consider is the *useful effect*, that is to say, the total effect, deducting the value which represents the transference of the weight of the man's body. This total effect is the greatest possible when the man ascends without a burthen; but the *useful* effect is then nothing: it is also nothing if the man be so much loaded as to be scarcely capable of moving: and consequently there exists between these two limits a value of the load such that the useful effect is a maximum. M. Coulomb supposes that the loss of quantity of action is proportional to the load (an hypothesis which experience confirms), whence he obtains an equation which, treated according to the rules of maxima and minima, gives 53 kilogrammes (117 lbs. avoird.) for the weight with which the man ought to be loaded, in order to produce during one day, by ascending stairs, the greatest useful effect: the quantity of action which results from this determination has for its value 56 kilogrammes ($123\frac{1}{2}$ lbs. avoird.) raised through one kilometer, or nearly 1094 yards. But this method of working is attended with a loss of three-fourths of the total action of men, and consequently costs four times as much as work in which, after having mounted a set of steps without any burthen, the man should suffer himself to fall by any means, so as to raise a weight nearly equal to that of his own body.

* The kilogramme is = 15443·5 grs. = 2·20626 lbs. avoirdupois.

From an examination of the work of men walking on a horizontal path, with or without a load, M. Coulomb concludes that the greatest quantity of action takes place when the men walk being loaded: and is to that of men walking under a load of 58 kilogrammes (128 lbs. avoird.) nearly as 7 to 4. The weight which a man ought to carry in order to produce the greatest *useful effect*, namely, that effect in which the quantity of action relative to the carrying his own weight is deducted from the total effect, is 50·4 kilogrammes, or 111·18 lbs. avoirdupois.

There is a particular case which always obtains with respect to burthens carried in towns, viz. that in which the men, after having carried their load, return unloaded for a new burthen. The weight they should carry in this case, to produce the greatest effect, is 61·25 kilogrammes ($135\frac{1}{8}$ lbs. avoird.). The quantity of useful action in this case compared with that of a man who walks freely and without a load is nearly as 1 to 5, or, in other words, he employs to pure loss $\frac{4}{5}$ of his power. By causing a man to mount a set of steps freely and without burthen, his quantity of action is at least double of what he affords in any other method of employing his strength.

When men labour in cultivating the ground, the whole quantity afforded by one during a day amounts to 100 kilogrammes elevated to one kilometer, that is, 220·6 lbs. raised 1094 yards. M. Coulomb comparing this work with that of men employed to carry burthens up an ascent of steps, or at the pile-engine, finds a loss of about $\frac{1}{20}$ part only of the quantity of action which may be neglected in researches of this kind.

In estimating mean results we should not determine from experiments of short duration, nor should we make any deductions from the exertions of men of more than ordinary strength. The mean results have likewise a relation to climate. "I have caused," says M. Coulomb, "extensive works to be executed by the troops at Martinico, where the thermometer (of Reaumur) is seldom lower than 20° (77° of Fahrenheit). I have executed works of the same kind by the troops in France: and I can affirm that under the fourteenth degree of latitude, where men are almost always covered with perspiration, they are not capable of performing half the work they could perform in our climate *." *Bulletin de la Soc. Philomath.* No. 16.

* In the preceding account of the effects of human exertion, since the professed object was to state the mean results of regular and uniform labour, we have taken no notice either of feats of extraordinary strength, or of such as were in *appearance* such, while in reality they were the effect of contrivance and skill, and might have been performed by almost any men who had sufficient knowledge of the subject to

68. A porter in London is accustomed to carry a burden of 200 lbs. at the rate of three miles an hour; and a couple of

exert their strength under similar circumstances. But as it may be expected that some notice should be taken of such matters, we shall throw into this note a few remarks which have formerly been made in reference to them.

M. de la Hire, in an *Examination of the Force of Men*, given in the Memoirs of the Academy of Sciences for 1699, says, "There are men whose spirits flow so abundantly and so swiftly into their muscles, that they exert three or four times more strength than others do; and this seems to me to be the natural reason of the surprising strength that we see in some men who carry and raise weights which two or three ordinary men can hardly sustain, though these men be sometimes but of a moderate stature, and rather appear weak than strong. There was a man in this country a little while ago, who would carry a very large anvil, and of whom were reported several wonderful feats of strength. But I saw another at Venice, who was but a lad, and did not seem able to carry above 40 or 50 lbs. with all possible advantages; yet this young fellow, standing upon a table, raised from the earth, and sustained off the ground, an ass, by means of a broad girt, which, going under the creature's belly, was hung upon two hooks that were fastened to a plat of small cords coming down in tresses from the hair on each side of the lad's head, which were in no great quantity. And all this great force *depended only upon the muscles of the shoulders and those of the loins:* for he stooped at first whilst the hooks were fastened to the girt, and then raised himself, and lifted up the ass from the ground, bearing with his hands upon his knees. He raised also in the same manner other weights that seemed heavier, and used to say he did with more ease, because the ass kicked and struggled when first lifted from the ground."

Dr. Desaguliers, in some annotations upon De la Hire's paper, says, "What he attributes here to the *muscles of the loins* was really performed by the extensors of the legs; for the young man's stooping with his hands upon his knees was not with his body forwards and his knees stiff, but his body upright and his knees bent, so as to bring the two cords with which he lifted to be in the same plane with his ancles and the heads of his thigh bones; by which means the line of direction of the man and the whole weight came between the strongest part of his two feet, which are the supports: then as he extended his legs he raised himself, without changing the line of direction. That this must have been the manner I am pretty well assured of, by not only observing those that perform such feats, but having often tried it myself. As for the muscles of the loins, they are incapable of that strain, being above six times weaker than the extensors of the legs; at least I found them so in myself.

"About the year 1716, having the honour of showing a great many experiments to his late majesty king George the first, his majesty was desirous to know whether there was any fallacy in those feats of strength that had been shown half a year before, by a man, who seemed by his make to be no stronger than other men: upon this I had a frame of wood made to stand in (and to rest my hands upon), and with a girdle and chain lifted an iron cylinder made use of to roll the garden, sustaining it easily when once it was up. Some noblemen and gentlemen who were present tried the experiment afterwards, and lifted the roller; some with more ease, and some with more difficulty, than I had done. This roller weighed 1900 lbs. as the gardener told us. Afterwards I tried to lift 300 lbs. with my hands, (viz. two pails with 150 lbs. of quicksilver in each), which I did indeed raise from the ground, but strained my back so as to feel it three or four days: which shows that, in the same person, the muscles of the loins (which exerted their force in this last experiment) are more than six times weaker than the extensors of the legs; for I felt no inconveniency from raising the iron roller."

During the time occupied in printing the second volume of Dr. Desaguliers' Philosophy, a man of great natural strength exhibited himself in London: of this man the doctor gives an account, from which the following is extracted:

"*Thomas Topham*, born in London, and now about 31 years of age, five feet ten inches high, with muscles very hard and prominent, was brought up a carpenter, which trade he practised till within these six or seven years that he has showed feats of strength: but he is entirely ignorant of any art to make his strength more surprising.

chairmen continue at the pace of four miles an hour, under a load of 300 lbs. But these exertions, Professor Leslie remarks,

Nay, sometimes he does things which become more difficult by his disadvantageous situation; attempting, and often doing, what he hears other strong men have done, without making use of the same advantages.

"About six years ago he pulled against a horse, sitting upon the ground with his feet against two stumps driven into the ground, but without the advantages which might have been attained by placing himself in a proper situation; the horse, however, was not able to move him, and he thought he was in the right posture for drawing against a horse: but when, in the same posture, he attempted to draw against two horses, he was pulled out of his place by being lifted up, and had one of his knees struck against the stumps, which shattered it so, that, even to this day, the *patella*, or knee pan, is so loose, that the ligaments of it seem either to be broken or quite relaxed, which has taken away most of the strength of that leg."

The exploits which Dr. Desaguliers saw him perform were these:

"1. By the strength of his fingers (only rubbed in coal ashes to keep them from slipping) he rolled up a very strong and large pewter dish.

"2. He broke seven or eight short and strong pieces of tobacco-pipe with the force of his middle finger, having laid them on the first and third finger.

"3. Having thrust in under his garter the bowl of a strong tobacco-pipe, his legs being bent, he broke it to pieces by the tendons of his hams, without altering the bending of his leg.

"4. He broke such another bowl between his first and second finger, by pressing his fingers together sideways.

"5. He lifted a table six feet long, which had half a hundred weight hanging at the end of it, with his teeth, and held it in an horizontal position for a considerable time. It is true the feet of the table rested against his knees; but, as the length of the table was much greater than its height, that performance required a great strength to be exerted by the muscles of his loins, those of his neck, the *masseter* and *temporal* (muscles of the jaws), besides a good set of teeth.

"6. He took an iron kitchen poker, about a yard long, and three inches in circumference, and, holding it in his right hand, he struck upon his bare left arm, between the elbow and the wrist, till he bent the poker nearly to a right angle.

"7. He took such another poker, and holding the ends of it in his hands, and the middle against the back of his neck, he brought both ends of it together before him; and, what was yet more difficult, he pulled it almost straight again: because the muscles which separate the arms horizontally from each other are not so strong as those that bring them together.

"8. He broke a rope of about two inches in circumference, which was in part wound about a cylinder of four inches diameter, having fastened the other end of it to straps that went over his shoulders. But he exerted more force to do this than any other of his feats, from his awkwardness in going about it; for the rope yielded and stretched as he stood upon the cylinder, so that when the extensors of the legs and thighs had done their office in bringing his legs and thighs straight, he was forced to raise his heels from their bearings, and use other muscles that are weaker. But if the rope had been so fixed that the part to be broken had been short, it would have been broken with four times less difficulty.

"9. I have seen him lift a rolling stone of about 800 lbs. with his hands only, standing in a frame above it, and taking hold of a chain that was fastened to it. By this, I reckon he may be almost as strong again as those who are generally reckoned the strongest men, they generally lifting no more than 400 lbs. in that manner. The weakest men who are in health, and not too fat, lift about 125 lbs. having about half the strength of the strongest.

"N. B. This sort of comparison is chiefly in relation to the muscles of the loins; because in doing this one must stoop forwards a little. We must also add the weight of the body to the weight lifted. So that if the weakest man's body weigh 150 lbs. that added to 125 lbs. makes the whole weight lifted by him to be 275 lbs. Then if the stronger man's body weighs also 150 lbs. the whole weight lifted by him will be 550 lbs. that is 400 lbs. and the 150 lbs. which his body weighs. *Topham* weighs

are greatly inferior to the labour performed by porters in Turkey, the Levant, and generally on the shores of the Mediterranean. At Constantinople, an Albanian porter will carry 800 or 900 lbs. on his back, stooping forward, and assisting his steps by a short staff. At Marseilles it is affirmed that four porters carry the immense load of nearly two tons, by means of soft hods passing over their heads, and resting on their shoulders, with the ends of poles, from which the goods are suspended.

69. With regard to the magnitude of the comparative efforts of man in different employments, the late Mr. Robertson Bu-

about 200 lbs. which, added to the 800 lbs. that he lifts, makes 1000 lbs. But he ought to lift 900 lbs. besides the weight of his body, to be as strong again as a man of 150 lbs. weight who can lift 400 lbs."

Again: "About thirty years ago one *Joyce*, a Kentish man, famous for his great strength, showed several feats in London and the country, which so much surprised the spectators, that he was by most people called *the second Sampson*. But though the postures which he had learnt to put his body into, and found out by practice without any mechanical theory, were such as would make a man of common strength do such feats as would appear surprising to every one who did not know the advantage of those positions of the body; yet nobody then attempted to draw against horses, or raise great weights, or to do any other thing in imitation of him: because, as he was very strong in the arms, and grasped those that tried his strength that way so hard that they were obliged immediately to desire him to desist, his other feats (wherein his manner of acting was chiefly owing to the mechanical advantage gained by the position of his body) were entirely attributed to his extraordinary strength.

"But when he had been gone out of England, or had ceased to show his performances for eight or ten years, men of ordinary strength found out the way of making such advantage of the same postures as *Joyce* had put himself into as to pass for men of more than common strength, by drawing against horses, breaking ropes, lifting vast weights, &c. (though they could in none of the postures really perform so much as Joyce, yet they did enough to amaze and amuse, and get a great deal of money), so that every two or three years we had a *new second* Sampson.

"About fifteen years ago a *German* of middle size, and but ordinary strength, showed himself at the *Blue Posts*, in the Haymarket, and by the contrivances abovementioned passed for a man of uncommon strength, and got considerable sums of money by the daily concourse of spectators. After having seen him once, I guessed at his manner of imposing upon the multitude; and being resolved to be fully satisfied in the manner, I took four very curious persons with me to see him again, viz. the lord marquis of Tullibardin, Dr. Alexander Stuart, Dr. Pringle, and a mechanical workman who used to assist me in my courses of experiments. We placed ourselves in such manner round the operator, as to be able to observe nicely all that he did; and found it so practicable, that we performed several of his feats that evening by ourselves, and afterwards I did the most of the rest, as I had a frame to sit in to draw, and another to stand in and lift great weights, together with a proper girdle and hooks. I likewise showed some of the experiments before the Royal Society; and ever since at my experimental lectures I explain the reason of such performances, and take any person of ordinary strength that has a mind to try, who can easily do all that the German above-mentioned used to do, without any danger of extraordinary straining, by making use of my apparatus for that purpose."

The Doctor then proceeds to explain the principles on which these achievements depended, and illustrates his positions by various diagrams. He likewise describes some contrivances to determine the strength which men exert in different ways; for an account of the chief of which, the reader may turn to the article Steelyard, *to ascertain the Strength of Men*, in a subsequent part of this volume.

chanan ascertained, that in working a pump, in turning a winch, in ringing a bell, and rowing a boat, the dynamic results are as the numbers 100, 167, 227, and 248.

According to the interesting experiments described in M. Hachette's *Traité des Machines*, the dynamic unit being *the weight of a cubic metre of water raised to the height of one metre* [that is, 2208 lbs. avoird. or 4 hogsheads raised to the height of 3·281 feet, or 1·3124 hogsheads to the height of 10 feet], we have the following measures, at a medium, of the daily actions of men.

	Dynamic units.
1. A man marching $7\frac{1}{2}$ hours on a slope of 7 degrees, with a load of from 15 to 18 lbs.	225
2. Marching in a mountainous country without load	140
3. Carrier of wood up a ladder, his weight 123, his load 117 lbs.	109
4. Carrier of peat up steps, his own weight comprised	112 to 120
5. Man working at the cord of a pulley to raise the ram of a pile engine: three examples	75 40 48
6. A man drawing water from a well by means of a cord	71
7. Man working at a capstan	116
8. Man working at a capstan to raise water, mean of 24	110

The unit of transport, being the weight of a cubic metre of water, carried a metre (2208 lbs. 3·281 feet) upon a horizontal road, we have for the daily action

	Dynamic units.
1. A man travelling without load on a flat road, his weight 154 lbs. his journey $31\frac{1}{4}$ miles	3500
2. A soldier, carrying from 44 to 55 lbs. travelling $12\frac{1}{2}$ miles	1800 to 1900
3. Do. a forced march of 25 miles	2800
4. A French coal-porter, weight of the man not included	792 to 880
5. Porter with wheel-barrows, weight of the man not included	1015
6. Porter with a sledge	627
7. A man drawing a boat on a canal; 110310 lbs. conveyed $6\frac{7}{8}$ miles	550000

70. Among quadrupeds the most useful as a first mover of machinery is the *horse*. The strength of this animal is pro-

bably about six times that of a man. Desaguliers states the proportion as 5 to 1; coinciding with the deductions of Smeaton before mentioned. The French authors commonly reckon 7 men for 1 horse. As a mean between these, we took, in art. 378. vol. I. the proportion of 6 to 1, and stated the strength of a horse as equivalent to 420 lbs. at a dead pull. But the proportion is by no means constant, for it varies greatly according to the different kinds of work. Thus the worst way of applying the strength of a horse is to make him carry a weight up a steep hill; while the organization of a man fits him very well for this kind of labour: hence, *three* men climbing up such a hill with a weight of 100 lbs. each, will proceed faster than a horse with a load of 300 lbs. This, we believe, was first observed by M. de la Hire.

M. Schulze, in a paper inserted in the Memoirs of the Berlin Academy for 1783 *, has described a series of experiments instituted for the purpose of determining whether in estimating animal power, the formula $F = \varphi\,(1 - \frac{V}{W})^2 = \varphi\,(\frac{W - V}{W})^2$ [art. 377. vol. I.] or $F = \varphi\,(1 - \frac{V^2}{W^2})$ should be used; and proves clearly that the former deserves the preference. He assigns the mean value of human strength as equivalent to 29 or 30 pounds, with a velocity of $2\frac{1}{2}$ feet per second. But he estimates the entire effect of a horse exerting himself horizontally, as *fourteen* times that of a man. This, we apprehend, is far too high.

We are not acquainted with any series of experiments which have been made with a view of determining the weights horses can carry when moving up sloping roads, making given angles with the horizon: but, fortunately, this deficiency is not of much consequence, because the *carrying* of weights is far from the best manner of employing the strength of a horse. It is known, however, that, in general, a horse loaded with a man and his equipage, weighing altogether about 2 cwt. may, without being forced, travel, in 7 or 8 hours, the distance of 43000 yards, or nearly 25 miles, upon a good road. When a horse travels day after day without cessation, either the weight he carries or the distance passed over must undergo some diminution, as well as the time actually employed in travelling.

71. In the Memoirs of the French Academy for 1703 are inserted the comparative observations of M. Amontons, on the velocity of men and of horses; in which he states the velocity of a horse loaded with a man and walking to be rather more than $5\frac{1}{4}$ feet per second, or $3\frac{1}{2}$ miles per hour, and when going

* Published in the Phil. Mag. vol. xxxix. No. 168.

a moderate trot with the same weight to be about $8\frac{1}{2}$ feet per second, or about 6 miles per hour. These velocities, however, are somewhat less than what might have been taken for the mean velocities.

72. But the best way of applying the strength of horses is to make them draw weights in carriages, &c. To this kind of labour, therefore, the inquiries of experimentalists should be directed. A horse put into harness and making an effort to draw bends himself forward, inclines his legs, and brings his breast nearer to the earth; and this so much the more as the effort is the more considerable. So that when a horse is employed in drawing, his effort will depend, in some measure, both upon his own weight and that which he carries on his back.

Indeed it is highly useful to load the back of a drawing horse to a certain extent; though this, on a slight consideration, might be thought to augment unnecessarily the fatigue of the animal: but it must be considered that the mass with which the horse is charged vertically is added in part to the effort which he makes in the direction of traction, and thus dispenses with the necessity of his inclining so much forward as he must otherwise do; and may, therefore, under this point of view, relieve the draught more than to compensate for the additional fatigue occasioned by the vertical pressure. Carmen, and waggoners in general, are well aware of this, and are commonly very careful to dispose of the load in such a manner that the shafts shall throw a due proportion of the weight on the back of the shaft horse.

73. The best disposition of the traces during the time a horse is drawing is to be perpendicular to the position of the collar upon his breast and shoulders: when the horse stands at ease, this position of the traces is rather inclined upwards from the direction of the road; but when he leans forward to draw the load, the traces should then become nearly parallel to the plane over which the carriage is to be drawn; or, if he be employed in drawing a sledge, or any thing without wheels, the inclination of the the traces to the road, supposing it to be horizontal, should (from what we observed when treating of friction) be about $18\frac{1}{2}°$.

74. From the preceding observations it will be easy in most cases to adapt the size of the wheels to that of the animal which is to draw in the shafts, so that when he leans forward to his work the traces may be nearly parallel to the road, whether that road be horizontal or not: always recollecting that, if there be any variation from the parallel position, it must be rather inclining upwards than downwards; as the former will somewhat

diminish the friction, while the latter, instead of raising the wheels from any hollow into which they may fall, will tend to draw them down lower, and much increase the labour of the animal.

75. When several horses are harnessed one before another, so that they may all draw at the same load, and the slope on which they are drawing changes, as from DA to AB (fig. 6. pl. I.), the effort of the horse which draws along the road AB is decomposed into two parts, of which one tends to pull up the load, the other to pull *down* the horse which is in the shafts and is drawing along the slope DA. This latter composant is always greater as the traces of the foremost horse are the longer; and it may be worth while to find its values, and its augmentation with regard to an increase in the length of the traces. To this end let EA′ be the height above AD of the breast of the horse which draws in the shafts near the point A, and let ER and ER′ be two different lengths of the traces; the breast of the horse when harnessed to either of these traces being at the same distance from the plane AB′, that is, BR = B′R′ = EA′. Take EF = EF′ to represent the effort of the horse in the direction of the trace; draw Eq' parallel to DA, EQ perpendicular to BA produced, Eg parallel to AB, and Fq, F′q', perpendicular to Eq. The effort which tends to pull the horse down whose breast is at E is represented by Fq, when the breast of the other horse is at R, and by F′q' when it is at R′; and qE, q'E are the corresponding efforts tending to raise the load along the slope DA. Make EA′ = RB = R′B′ = a, ER = λ, ER′ = λ', angle A′EQ = qEg = supplem. DAB = s, and EF = EF′ = φ. Then, when the trace ER is used, the effort which tends to pull down the shaft horse when he just reaches the summit of the slope will be $= \varphi \cdot \sin q\text{EF} = \varphi$ sin (qEg − FEg), and the effort tending to raise the load will be $= \varphi$cos (qEg − FEg). In like manner, when the foremost horse draws by the trace ER′, the effort tending to pull down the shaft horse will be represented by φ sin (qEg' − F′Eg'), and that which tends to draw up the carriage by φ cos (qEg' − F′Eg').

Now we have sin F′Eg $= \frac{\text{R}g}{\text{ER}}$, and sin FE$g$ $= \frac{\text{R}'g'}{\text{ER}'} = \frac{\text{R}g}{\text{ER}'}$. But R$g$ = BR − EQ $= a - a \cos s = a(1 - \cos s)$. Recollecting, therefore, that the angles FEg, F′Eg, are always so small that the arcs differ very little from the sines, we have FEg $= \frac{a(1-\cos s)}{\lambda}$, and F′E$g'$ $= \frac{a(1-\cos s)}{\lambda'}$: these values being substituted in the preceding expressions, give

$$(1) \ldots \text{F}q = \varphi \sin\left(s - \frac{a(1-\cos s)}{\lambda}\right).$$

$$(2) \ldots F'q' = \varphi \sin\left(s - \frac{a(1-\cos s)}{\lambda'}\right).$$

$$(3) \ldots Eq = \varphi \cos\left(s - \frac{a(1-\cos s)}{\lambda}\right).$$

$$(4) \ldots Eq' = \varphi \cos\left(s - \frac{a(1-\cos s)}{\lambda'}\right).$$

Suppose, for example, that AB is horizontal, and that the ascent DA is such that for every 6 feet, as CN in a horizontal plane, the vertical rise NA shall be one foot: this slope is too steep for any common road, but may be sometimes met with in ascents from stone quarries, &c. In this case the angle s will be nearly 9° 28′, which, expressed in decimal parts of the radius, gives $s = 0\cdot16522$, and $\cos s = 0.98638$. Let the effort $\varphi = 200$ lbs., $a = 3\frac{1}{2}$ feet, $\lambda = 8$ feet, and $\lambda' = 12$ feet. Then shall we have,

$$(1) \ldots Fq = 200 \sin\left(0\cdot16522 - \frac{3\cdot5(1-0\cdot98638)}{8}\right)$$
$$= 200 \sin 9^\circ\, 7'\, 29'' = 31\cdot716 \text{ lbs.}$$

$$(2) \ldots F'q' = 200 \sin\left(0\cdot16522 - \frac{3\cdot5(1-0\cdot98638)}{12}\right)$$
$$= 200 \sin 9^\circ\, 14'\, 29'' = 32\cdot5 \text{ lbs.}$$

$$(3) \ldots Eq = 200 \cos 9^\circ\, 7'\, 29'' = 177\cdot27 \text{ lbs.}$$

$$(4) \ldots Eq' = 200 \cos 9^\circ\, 14'\, 29'' = 197\cdot404 \text{ lbs.}$$

Hence it appears, that the horse whose breast is at E is pulled downwards by the other horse, with a force equivalent to about 32 lbs.: this weight is small for a horse that is not fatigued; but we should consider, that when drawing up a steep road the animal's strength is much weakened, so that it may be obliged to yield to a very small effort. A lengthening of four feet to a trace of eight feet will produce an augmentation of $32\cdot25 - 31\cdot716 = 0\cdot534$ lbs. in the effort which tends to pull the shaft horse down, and a diminution of $197\cdot47 - 197\cdot404 = 0\cdot066$ lbs. in the effort which raises the load up the hill. These quantities are not considerable; but it appeared desirable to explain the method of ascertaining their magnitude. And it may be added, that when a horse pulls for only a short time, as a few minutes, he will often exert a force equivalent to 500 or 600 lbs.: in which case, the tendency to pull down a shaft horse rising a hill would be thrice as much as we have stated it above: a force against which no horse could stand in such a disadvantageous position.

76. When a horse is made to move in a circular path, as is often practised in mills and other machines moved by horses, it will be necessary to give the circle which the animal has to walk round the greatest diameter that will comport with the local and other conditions to which the motion must be sub-

jected. It is obvious, indeed, that, since a rectilinear motion is the most easy for the horse, the less the line in which he moves is curved, with the greater facility he will walk over it, and the less he need recline from a vertical position: and besides this, with equal velocity the centrifugal force will be less in the greatest circle, which will proportionally diminish the friction of the cylindrical part of the trunnions, and the labour of moving the machine. And, further, the greater the diameter of the horse-walk, the nearer the chord of the circle in which the horse draws is to coincidence with the tangent, which is the most advantageous position of the line of traction. On these accounts it is that, although a horse *may* draw in a circular walk of 18 feet diameter, yet in general it is advisable that the diameter of such a walk should not be less than 25 or 30 feet; and in many instances 40 feet would be preferable to either.

77. It has been stated by Desaguliers and some others, that a horse employed daily in drawing nearly horizontally can move, during eight hours in the day, about 200 lbs. at the rate of $2\frac{1}{2}$ miles per hour, or $3\frac{2}{3}$ feet per second. If the weight be augmented to about 240 or 250 lbs., the horse cannot work more than six hours a day, and that with a less velocity. And, in both cases, if he carry some weight, he will draw better than if he carried none (art. 72). M. Sauveur estimates the mean effort of a horse at 175 French, or 189 avoird. pounds, with a velocity of rather more than three feet per second: and this agrees very nearly with our deduction in art. 378. vol. I. But all these are probably too high to be continued for eight hours, day after day; for in our investigation just referred to we assumed 10 feet per second, as the utmost walking velocity of a horse; a velocity which we conceive no horse would be able to continue long. In another place Desaguliers states the mean work of a horse as equivalent to the raising a hogshead full of water (or 550 lbs.) 50 feet high in a minute. But Mr. Smeaton, to whose authority much is due, asserts, from a number of experiments, that the greatest effect is the raising 550 lbs. forty feet high in a minute. And, from some experiments made by the Society for the Encouragement of Arts, under the direction of Mr. Samuel Moore, it was concluded, that a horse moving at the rate of three miles an hour can exert a force of 80 lbs. Unluckily, we are not sufficiently acquainted with the nature of the experiments and observations from which these deductions were made, to institute an accurate comparison of their results. Neither of them ought to express what a horse can draw upon a carriage; because in that case friction only is to be overcome (after the load is once put into motion); so that a

middling horse, well applied to a cart, will often draw much more than 1000 lbs. The proper estimate would be that which measures the weight that a horse would draw up out of a well; the animal acting by a horizontal line of traction turned into the vertical direction by a simple pulley, or roller, whose friction should be reduced as much as possible. It would, indeed, be far the best, in all the instances of experiments, to use no such combinations of machinery as would make the velocity of the load or weight different from that of the animal: we could then readily compare the different results by means of the expression $M \propto (W-V)^2$, or $M \propto (W-V)^{\frac{9}{5}}$ (art. 378. vol. I.), where V represents the velocity in feet per second with which the animal moves the mass M, and W his greatest walking velocity, or that in which he can move no weight but his own. Thus might we obtain a mean estimate of the animal's strength at any one velocity, and could thence infer his maximum of useful effort; namely, that when V is nearly $\frac{1}{3}$W. As to the absolute power of the animal, it might be inferred in any case of raising a weight with his own velocity, by means of the formula $\phi = (M+H)V + Mgt$, where M and V are as before, H the weight of the horse, ϕ its power, $g = 32\frac{1}{6}$ feet the measure of the force of gravity, and t the time in seconds during which the animal continues his uniform exertion.

78. It follows, from what has been said, and from the consideration of the strengths of horses variously employed, such as waggon horses, dray horses, plough horses, heavy horses, light coach horses, &c. that what is called "*horse power*" is of so fluctuating and indefinite a nature, that it is perfectly ridiculous to assume it as a common measure, by which the force of steam-engines and other machines should be appreciated. In most of the deductions which have been hitherto made, we apprehend there may be something of temporary effort: and we think, on the whole, that about 70 lbs. at three miles an hour, or $4\frac{2}{5}$ feet per second, may be a fair estimate for the regular work of stout London cart horses; though we would infer, with Mr. Nicholson, "that the animal can double his strength for a short time, such as ten minutes, without receiving any injury from the exertion."

DESCRIPTIONS

OF

MACHINES:

ALPHABETICALLY ARRANGED.

AIR-PUMP is a machine by means of which the air may be exhausted out of proper vessels, so as to make what is popularly called a *vacuum*, but which is, in fact, only a very high degree of rarefaction.

The invention of this noble instrument, to which the present age is indebted for so many admirable discoveries, is ascribed to *Otto de Guericke*, a consul of Magdeburg, who exhibited his first public experiments with his pump before the emperor and the states of Germany at the breaking up of the imperial diet at Ratisbon, in the year 1654. Guericke, indifferent about the solitary possession of an invention which afforded such entertainment to the numerous persons who, from time to time, witnessed his experiments, gave a minute description of all his pneumatic apparatus to Gasper Schottus, professor of mathematics at Wirtemberg, who published it, with the consent of the inventor, with an account of some of its performances, first in 1657, in his *Mechanica Hydraulico-pneumatica;* and then, in 1664, in his *Technica Curiosa*. Guericke's own account was not published till 1672.

About the time of Guericke's invention the foundations of the Royal Society of London were laid. Boyle, Wren, Brounker, Wallis, and other learned men, held frequent meetings at Oxford, in which accounts were received and related of all important advances in the study of nature; and many experiments were exhibited. The researches of Galileo, Torricelli, and Pascal, concerning the pressure of the air, had greatly engaged

their attention, and thus prepared them for the invention of Guericke. Mr. Boyle, in particular, as soon as he heard what had been accomplished by the philosopher of Magdeburg, and before any description of his machine had been published, set about the construction of one to answer the same purposes; and succeeded in the attempt: though he frankly acknowledges that it was but seldom, and with great difficulty, that he could produce an extreme degree of rarefaction; such as it appeared, from the account of Schottus, was obtained by means of Guericke's machine.

Boyle's instrument was somewhat improved by Hawksbee, and further by Martin; with some slight modifications to particular views, it still retains the most approved form. The air-pump we described in art. 521. vol. I. is only so far varied from Hawksbee's improvement of Boyle's original contrivance, as to render it more portable. The machine, in its primitive state, is described in the article *Pneumatics, English Encyclopædia;* where, also, the successive improvements of Smeaton, Cuthbertson, &c. are described at large. See also the PANTOLOGIA.

Many other ingenious attempts have been made, during the last ten or twelve years, to improve the mechanism of the air-pump; to describe a fourth part of which would extend this article to more than its due length. Justice, however, to the authors of these improvements, as well as a desire to gratify the reader, induces us to refer to Nicholson's Journal, vols. I. and II. 4to. for descriptions of the air-pumps invented by Messrs. Prince, Sadler, Little, Sir G. Mackenzie, &c. and to Mr. Vince's Hydrostatics for an account of the pump used by that gentleman in his lectures.

Notwithstanding the many improvements which have successively followed each other in the construction of the air-pump, it was still, however, desirable that it should be further simplified in its mechanism, while it possessed the same advantages as attended those of more complicated structure. Cuthbertson, Haas, and some others, have so contrived their instruments, that their mechanical power, and not the pressure of air, should open the valves: but, although the air-pumps invented by these gentlemen are exceedingly ingenious, they are in some respects so complex, that it must be very difficult for many persons who possess these instruments to clean them, or to keep them in proper order for experiments.

Mr. N. Mendelsohn, a mathematical instrument-maker, of Surrey-street, Black-friars, having reflected upon the difficulties just alluded to, was led to the construction of a more

simple air-pump, which is capable of being put together in less than half an hour, whenever it is cleaned, and requires that operation very seldom. He has rejected the tube which, in common air-pumps, leads from the valves to the receiver, together with the cock that serves to shut this pipe: the receiver is placed immediately upon the valves, these being put on the top of the cylinders, which consequently required the rackwork and pinion being underneath, and inverted the whole instrument. See the drawing, pl. IV. where AB and CD represent the two cylinders of glass ground and polished inside. E and F are the two valves that allow the cylinders to communicate with the receiver O through two very short canals AB and CD (fig. 2. pl. IV.) and the cock G. Two other valves that open into the atmosphere are within the covers *i* and *k*, as may be seen in *fig.* 1, where *e* represents one of them. MN is the receiver-plate of glass ground flat; PQ a barometer-gauge, upon the plan of the first Torricellian tube, as the easiest to construct and the most infallible in its effects. It will be found to be here quite out of the way, secure from being broken by accident, and the most in sight. HK and IL are two brass pillars that support the whole. RSVW the usual rackwork, having a double winch *lm*, which, upon trial, will be found preferable to a single one.

It will now be necessary to show how this pump acts, in which it will be sufficient to explain the action of one cylinder, because the other is in all parts like it. E is a conical metallic valve, from which a canal goes through the cock G up to the receiver, as is seen in fig. 1 and 2, where all the parts are marked with the same letters. ET is a steel rod going through a leather box in the piston U. The top of this rod is fixed to the valve E, and its bottom part slides in a small hole with an allowance of 0·1 inch up and downward; consequently the valve E can move no further. When the piston descends, it first opens the valve by pushing the rod to the bottom of the hole. Then it slides down along the rod ET, and the air from the receiver has now free access to the cylinder. When the piston returns it lifts the rod ET, and thus shuts up the valve. Then the piston slides again along the rod up to the top of the cylinder, condensing the air above it, which air, by the least condensation, opens a valve *e*, fig. 2, and escapes freely into the atmosphere. This last valve has neither spring nor additional weight to shut it, but shuts by its own weight (about a quarter of an ounce) as soon as the piston is arrived at the top of the cylinder.

The cylinders are made of glass, *and the pistons of tin, so well fitted as to be air-tight, without the interposition of any leathers.*

The friction of these two bodies is small beyond expectation, a sufficient proof that they will be durable. They possess the further advantage of being capable of standing for even six months, after which time they will serve without being cleaned or repaired, because they are not liable to be corroded by the oil which they contain, an inconvenience too general in brass cylinders. After all, if the present pump should want cleaning, it is an easy operation to take off the top piece *gh*, by unscrewing the nuts H and I, when this piece, with all the apparatus upon it, will come off. Then each cylinder may very easily be slid off from the piston, wiped out and replaced, after having greased it inside with a little of the cleanest sweet oil: the top is then to be put again in its place, and the two nuts H and I being screwed upon it, the instrument is ready. Neither racks nor pinion need to be taken out of their places, the cylinders standing above them.

The cock is constructed so, that, being in the situation represented in fig. 1, the communication is open between the cylinders, the receiver, and the barometer-gauge, and, by a quarter of a revolution, the cylinders are excluded, the receiver and gauge being still left in communication. A little stopper in fig. 2, ground into the cock, being open, air is admitted to the receiver, if required.

The receiver-plate is of glass ground flat, as was mentioned before: this will be found preferable to brass, because cleaner, and never corroded by acids or water; it will besides often prove very convenient in making electrical experiments in the vacuum.

The whole instrument is fixed upon a mahogany table, which serves as a stand for it.

Mr. Mendelsohn concludes his description by observing that "neither the employing of glass cylinders nor the method of opening the valves is new; but, for aught he knows, this is the first instrument of the kind ever executed: and the idea of putting the valves at top, and thus simplifying the instrument, seems to have escaped the attention of the eminent artists, both here and abroad, as, to my best knowledge, it has never been done or described any where. The metallic pistons, without leathering, must certainly add to the durability, and diminish the great labour that usually attends working an air-pump." (*Nicholson's Journal, New Series, No.* 39.)

Mr. Vream, who was Dr. Desaguliers's operator for philosophical machines, made such an alteration in Hawksbee's air-pump, as produced the alternate reciprocating motion of the pistons, without turning the handle to and fro: while the handle turns constantly one way in its operation, a crank, by means of

two leading pieces, gives the wheel that moves the racks a motion of about two-thirds (or more when required) of its circumference, every time the crank goes round. The advantages which Mr. Vream thought would result from this alteration, he describes in the following words: "I hope I have improved Mr. Hawksbee's pump by a contrivance whereby in turning the winch quite round the *emboli*, or pistons, are alternately raised and depressed: whereas in Mr. Hawksbee's way, the moving of the hand backward and forward is not only more troublesome, but shakes the pump; because it is required to press the barrel hard against the bottom piece under the barrels, to discharge the air from the valves at every stroke. Besides if the pump should at any time happen to leak, when an experiment should be made in haste; you may exhaust so fast this way as to make your experiment without being at the trouble to pull the pump to pieces, in order to make it tight, except in such cases as require the recipient to be perfectly exhausted."

Fig. 11. pl. III. will show in what this improvement of Mr Vream's consists. The axis DB on which the crank A*ab* and handle BF turn, is perpendicular to the plane of the wheel WE which moves the racks S, T: two leaders N, N, of equal length, are hung by one end upon the crank A*a*, and by the other upon the two ends of a pin I which passes through the wheel at a suitable distance from the centre. While the crank is rising the pin I is raised from its position in the figure to some higher point, as R, thus causing the wheel to turn upon its centre E, and raise the rack S, while it depresses the rack T: afterwards, while the crank is descending through the other half of its revolution, the pin is pushed back again from R to I, the wheel E turns the contrary way, the rack T is raised, and S depressed. So the racks are alternately raised and depressed as the circular motion of the handle F carries round the crank A*a*. The radius *ab* of the crank must be rather less than the distance EI of the pin I from the centre of the wheel, in order to ensure the alternate motion of the pistons: and the more extensive the motion of these is required to be with respect to the motion of the crank, the more must the radius of the wheel EW exceed the distance EI.

This contrivance, however ingenious, has been seldom applied to air-pumps; probably because there is a considerable variation of requisite moving force in the different parts of the revolution of the crank; a variation which may produce jolts in the motion. But this inequality of force upon the crank, being occasioned by the variable obliquity in the position of the leaders N, N, may be much reduced by making the distances *ab*, EI, as small as

can be conveniently, with respect to the length *aI* of the leaders.

ANEMOMETER. See art. 49. of the introductory part of this volume.

ATWOOD'S MACHINE, the name which is now commonly applied to the ingenious apparatus invented by the late Mr. Atwood of Trinity college, Cambridge, to illustrate the doctrines of accelerated motion. This machine has been found to answer the purpose far more completely than any other; subjecting to experimental examination the quantity of matter moved, the measure of the force which moves it, the space described from quiescence, the time of description, and the velocity acquired. The theory of this instrument depends upon the principles exhibited in art. 267. vol. I. But we shall here give so much of the theory and description as seems necessary to show its nature and use, chiefly in the words of the ingenious inventor.

1. *Of the mass moved.*—In order to observe the effects of the moving force, which is the object of any experiment, the interference of all other forces should be prevented: the quantity of matter moved, therefore, considering it before any impelling force has been applied, should be without weight; for although it be impossible to abstract the natural gravity or weight from any substance whatever, yet the weight may be so counteracted as to be of no sensible effect in experiments. Thus in the instrument constructed to illustrate this subject experimentally, A, B, fig. 1. pl. V. represent two equal weights affixed to the extremities of a very fine and flexible silk line: this line is stretched over a wheel or fixed pulley *abcd*, moveable round an horizontal axis: the two weights A, B, being precisely equal and acting against each other, remain in equilibrio; and when the least weight is superadded to either (setting aside the effects of friction), it will preponderate. When A, B, are set in motion by the action of any weight m, the sum $A+B+m$ would constitute the whole mass moved, but for the inertia of the materials which must necessarily be used in the communication of motion: these materials consist of, 1. The wheel *abcd*, over which the line sustaining A and B passes. 2. The four friction-wheels, on which the axle of the wheel *abcd* rests: the use of these wheels is to prevent the loss of motion, which would be occasioned by the friction of the axle if it revolved on an immoveable surface. 3. The line by which the bodies A and B are connected, so as when set in motion to move with equal velocities. The weight and inertia of the line are too small to have sensible effect on the experiments; but the inertia of the other materials just mentioned constitute a considerable propor-

tion of the mass moved, and must be taken into account. Since when A and B are put in motion, they must necessarily move with a velocity equal to that of the circumference of the wheel *abcd*, to which the line is applied; it follows, that if the whole mass of the wheels were accumulated in this circumference, its inertia would be truly estimated by the quantity of matter moved: but since the parts of the wheels move with different velocities, their effects in resisting the communication of motion to A and B by their inertia will be different; those parts which are furthest from the axis resisting more than those which revolve nearer in a duplicate proportion of those distances. If the figures of the wheels were regular, from knowing their weights and figures, the distances of their centres of gyration from their axes of motion would become known, and consequently an equivalent weight, which being accumulated uniformly in the circumference *abcd*, would exert an inertia equal to that of the wheels in their constructed form. But as the figures are wholly irregular, recourse must be had to experiment, to assign that equivalent quantity of matter, which being accumulated uniformly in the circumference of the wheel *abcd*, would resist the communication of motion to A in the same manner as the wheels.

In order to ascertain the inertia of the wheel *abcd* with that of the friction-wheels, the weights A, B, being removed, the following experiment was made. A weight of thirty grains was affixed to a silk line (the weight of which was not so much as $\frac{1}{4}$th of a grain, and consequently too inconsiderable to have sensible effect in the experiment); this line being wound about the wheel *abcd*, the weight 30 grains by descending from rest communicated motion to the wheel, and by many trials was observed to describe a space of about $38\frac{1}{2}$ inches in 3 seconds. From these data the equivalent mass or inertia of the wheels will be known from this rule:

Let a weight P (fig. 2.) be applied to communicate motion to a system of bodies by means of a very slender and flexible line going round the wheel SLDIM, through the centre of which the axis passes (G being the common centre of gravity, R the centre of gravity of the matter contained in this line, and O the centre of oscillation). Let this weight descend from rest through any convenient space s inches, and let the observed time of its descent be t seconds; then if l be the space through which bodies descend freely by gravity in one second, the equivalent weight sought $= \frac{W \times SR \times SO}{SD^2} = \frac{P \times t^2 l}{s} - P$. See art. 314. vol. I.

Here we have $p=30$ grains, $t=3$ seconds, $l=193$ inches, $s=38{\cdot}5$ inches; and $\frac{P\times t^2 l}{s}-P=\frac{30\times 9\times 193}{385}-30=1323$ grains or $2\frac{3}{4}$ ounces.

This is the inertia equivalent to that of the wheel *abcd*, and the friction-wheels together: for the rule extends to the estimation of the inertia of the mass contained in all the wheels.

The resistance to motion therefore arising from the wheels' inertia will be the same as if they were absolutely removed, and a mass of $2\frac{3}{4}$ ounces were uniformly accumulated in the circumference of the wheel *abcd*. This being premised, let the boxes A and B, fig. 1, be replaced, being suspended by the silk line over the wheel or pulley *abcd*, and balancing each other: suppose that any weight m be added to A so that it shall descend, the exact quantity of matter moved, during the descent of the weight A, will be ascertained, for the whole mass will be $A+B+m+2\frac{3}{4}$ oz.

In order to avoid troublesome computations in adjusting the quantities of matter moved and the moving forces, some determinate weight of convenient magnitude may be assumed as a standard, to which all the others are referred. This standard weight in the subsequent experiments is $\frac{1}{4}$ of an ounce, and is represented by the letter m. The inertia of the wheels being therefore $=2\frac{3}{4}$ ounces, will be denoted by $11m$. A and B are two boxes constructed so as to contain different quantities of matter, according as the experiment may require them to be varied: the weight of each box, including the hook to which it is suspended, $=1\frac{1}{2}$ oz. or according to the preceding estimation, the weight of each box will be denoted by $6m$; these boxes contain such weights as are represented by fig. 3. each of which weighs an ounce, so as to be equivalent to $4m$; other weights of $\frac{1}{2}$ oz. $=2m$, $\frac{1}{4}=m$, and aliquot parts of m, such as $\frac{1}{2}$, $\frac{1}{4}m$, may be also included in the boxes, according to the conditions of the different experiments hereafter described.

If $4\frac{3}{4}$ oz. or $19m$, be included in either box, this, with the weight of the box itself, will be $25m$; so that when the weights A and B, each being $25m$, are balanced in the manner above represented, their whole mass will be $50m$, which being added to the inertia of the wheels $11m$, the sum will be $61m$. Moreover, three circular weights, such as that which is represented at fig. 4. are constructed; each of which $=\frac{1}{4}$ oz. or m: if one of these be added to A and one to B, the whole mass will now become $63m$, perfectly in equilibrio, and moveable by the least weight added to either (setting aside the effects of friction), in the same manner precisely as if the same weight or force were

applied to communicate motion to the mass $63m$, existing in free space and without gravity.

2. *The moving force.* Since the natural weight or gravity of any given substance is constant, and the exact quantity of it easily estimated, it will be convenient here to apply a weight to the mass A as a moving force: thus, when the system consists of a mass $=63m$, according to the preceding description, the whole being perfectly balanced, let a weight $\frac{1}{4}$ oz. or m, such as is represented in fig. 5. be applied on the mass A; this will communicate motion to the whole system: by adding a quantity of matter m to the former mass $63m$, the whole quantity of matter moved will now become $64m$; and the moving force being $=m$, this will give the force which accelerates the descent of $A = \frac{m}{64m}$, or $\frac{1}{64}$ part of the accelerating force by which the bodies descend freely towards the earth's surface.

By the preceding construction, the moving force may be altered without altering the mass moved: for suppose the three weights m, two of which are placed on A, and one on B, to be removed, then will A balance B. If the weights $3m$ be all placed on A, the moving force will now become $3m$, and the mass moved $64m$ as before, and the force which accelerates the descent of $A = \frac{3m}{64m} = \frac{3}{64}$ parts of the force by which gravity accelerates bodies in their free descent to the surface.

Suppose it were required to make the moving force $2m$, the mass moved continuing the same. In order to effect this, let the three weights, each of which $=m$, be removed; A and B will balance each other; and the whole mass will be $61m$: let $\frac{1}{2}m$, fig. 5, be added to A, and $\frac{1}{2}m$ to B, the equilibrium will still be preserved, and the mass moved will be $62m$; now let $2m$ be added to A, the moving force will be $2m$, and the mass moved $64m$, as before; wherefore the force of acceleration $=\frac{1}{32}$ part of the acceleration of gravity. These alterations in the moving force may be made with great ease and convenience in the more obvious and elementary experiments, there being no necessity for altering the contents of the boxes A and B: but the proportion and absolute quantities of the moving force and mass moved may be of any assigned magnitude, according to the conditions of the proposition to be illustrated.

3. *Of the space described.* The body A, fig. 1, descends in a vertical line; and a scale about 64 inches in length graduated into inches and tenths of an inch is adjusted vertically, and so placed that the descending weight A may fall in the middle of a square stage, fixed to receive it at the end of the descent: the beginning of the descent is estimated from 0 on the scale, when

the bottom of the box A is on a level with 0. The descent of A is terminated when the bottom of the box strikes the stage, which may be fixed at different distances from the point 0; so that by altering the position of the stage, the space described from quiescence may be of any given magnitude less than 64 inches.

4. *The time of motion* is observed by the beats of a pendulum, which vibrates seconds; and the experiments, intended to illustrate the elementary propositions, may be easily so constructed that the time of motion shall be a whole number of seconds: the estimation of the time, therefore, admits of considerable exactness, provided the observer takes care to let the bottom of the box A begin its descent precisely at any beat of the pendulum; then the coincidence of the stroke of the box against the stage, and the beat of the pendulum at the end of the time of motion, will show how nearly the experiment and the theory agree together. There might be various mechanical devices thought of for letting the weight A begin its descent at the instant of a beat of the pendulum W: let the bottom of the box A, when at 0 on the scale, rest on a flat rod, held in the hand horizontally, its extremity being coincident with 0, by attending to the beats of the pendulum; and with a little practice the rod which supports the box A may be removed at the moment the pendulum beats, so that the descent of A shall commence at the same instant.

5. *Of the velocity acquired.* It remains only to describe in what manner the velocity acquired by the descending weight A, at any given point of the space through which it has descended, is made evident to the senses. The velocity of A's descent being continually accelerated, will be the same in no two points of the space described. This is occasioned by the constant action of the moving force; and since the velocity of A at any instant is measured by the space which would be described by it, moving uniformly for a given time with the velocity it had acquired at that instant, this measure cannot be experimentally obtained, except by removing the force by which the descending body's acceleration was caused.

In order to show in what manner this is affected practically, let us again suppose the boxes A and B $=25m$ each, so as together to be $=50m$; this with the wheel's inertia $11m$, will make $61m$; now let m, fig. 3. be added to A, and an equal weight m to B, these bodies will balance each other, and the whole mass will be $63m$. If a weight m be added to A, motion will be communicated, the moving force being m, and the mass moved $64m$. In estimating the moving force, the circular weight $=m$ was made use of as a moving force: but for the present purpose of showing the velocity acquired, it will be convenient

to use a flat rod, the weight of which is also $= m$. Let the bottom of the box A be placed on a level with 0 on the scale, the whole mass being as described above $= 63m$, perfectly balanced in equilibrio. Now let the rod, the weight of which $= m$, be placed on the upper surface of A; this body will descend along the scale precisely in the same manner as when the moving force was applied in the form of a circular weight. Suppose the mass A, fig. 6, to have descended by constant acceleration of force m, for any given time, or through a given space: let a circular frame be so affixed to the scale, contiguous to which the weight descends, that A may pass centrally through it, and that this circular frame may intercept the rod m, by which the body A has been accelerated from quiescence. After the moving force m has been intercepted at the end of the given space or time, there will be no force operating on any part of the system which can accelerate or retard its motion: this being the case, the weight A, the instant after m has been removed, must proceed uniformly with the velocity which it had acquired that instant: in the subsequent part of its descent, the velocity, being uniform, will be measured by the space described in any convenient number of seconds.

Other uses of the instrument it is needless to describe particularly, but it may not be improper to mention some of them; such as the experimental estimation of the velocities communicated by the impact of bodies elastic and non-elastic; the quantity of resistance opposed by fluids, as well as for various other purposes. These uses we shall not insist on; but the properties of retarded motion being a part of the present subject, it may be necessary to show in what manner the motion of bodies resisted by constant forces are reduced to experiment by means of the instrument above described, with as great ease and precision as the properties of bodies uniformly accelerated. A single instance will be sufficient: Thus, suppose the mass contained in the weights A and B, fig. 6, and the wheels to be $61m$, when perfectly in equilibrio; let a circular weight m be applied to B, and let two long weights or rods, each $= m$, be applied to A, then will A descend by the action of the moving force m, the mass moved being $64m$: suppose that when it has described any given space by constant acceleration, the two rods m are intercepted by the circular frame above described, while A is descending through it, the velocity acquired by that descent is known; and when the two rods are intercepted, the weight A will begin to move on with the velocity acquired, being now retarded by the constant force m; and since the mass moved is $62m$, it follows that the force of retardation will be $\frac{1}{62}$ part of that force whereby gravity retards bodies thrown perpendicularly

upwards. The weight A will therefore proceed along the graduated scale in its descent with an uniformly retarded motion, and the space described, times of motion, and velocities destroyed by the resisting force, will be subject to the same measures as in the examples of accelerated motion above described.

In the foregoing descriptions, two suppositions have been assumed, neither of which is mathematically true; but it may be easily shown that they are so in a physical sense: the errors occasioned by them in practice being insensible.

1. The force which communicates motion to the system has been assumed constant; which will be true only on a supposition that the line, at the extremities of which the weights A and B, fig. 1, are affixed, is without weight. In order to make it evident that the line's weight and inertia are of no sensible effect, let a case be referred to, wherein the body A descends through 48 inches from rest by the action of the moving force m, when the mass moved is $64m$; the time wherein A describes 48 inches is increased by the effects of the line's weight by no more than $\frac{312}{100000}$th parts of a second; the time of descent being 3·9896 seconds, when the string's weight is not considered, and the time when the string's weight is taken into account $=$ 4·0208 seconds; the difference between which is wholly insensible by observation.

2. The bodies have also been supposed to move in vacuo, whereas the air's resistance will have some effect in retarding their motion; but as the greatest velocity communicated in these experiments cannot much exceed that of about 26 inches in a second (suppose the limit 26·2845), and the cylindrical boxes being about $1\frac{3}{4}$ inches in diameter, the air's resistance can never increase the time of descent in so great proportion as that of 240 : 241; its effects therefore will be insensible in experiment.

The effects of friction are almost wholly removed by the friction wheels; for when the surfaces are well polished and free from dust, &c. if the weights A and B be balanced in perfect equilibrio, and the whole mass consists of $63m$, according to the example already described, a weight of $1\frac{1}{2}$ grain, or at most 2 grains, being added either to A or B, will communicate motion to the whole; which shows that the effects of friction will not be so great as a weight of $1\frac{1}{2}$ or two grains. In some cases, however, especially in experiments relating to retarded motion, the effects of friction become sensible; but may be very readily and exactly removed by adding a small weight of 1·5 or 2 grains to the descending body, taking care that the weight added is such as is in the least degree smaller than that which is just sufficient to set the whole in motion, when A and B are equal,

and balance each other before the moving force is applied. (*Atwood on Motion*, p. 316.)

BALANCE, as distinguished from the Steelyard, is a lever with equal arms, whose fulcrum or centre of motion is situated immediately above the centre of gravity of the beam, when horizontal: it is used chiefly in determining the equality or difference in the weights of different bodies.

Some remarks on the nature of the balance were made when we treated of the lever in the first volume; where also we showed how to correct the deception occasioned by a false balance: in addition to what was there stated, we shall now present a few such observations as may be most serviceable in directing the accurate construction of this instrument.

1. The axis of motion of the balance should be above the centre of gravity of the beam.

2. A slender index, or *tongue* (as it is called), passes through the centres of gravity and motion of the beam, perpendicular to its axis: by this index the horizontal position of the beam, when loaded, in the comparison of weights, is determined.

3. When the balance unloaded is quiescent, and therefore horizontal, if the index which passes through the fulcrum be directed to any fixed point; and again when the balance is reversed, it be directed to the same fixed point; it is in the right line which joins the centre of gravity and the fulcrum.

By this means the position of the index is adjusted.

4. The perpendicular distances of the points of application of the weights to be compared, from the right line which joins the centres of gravity and of motion, should be equal, that is, the arms of the balance ought to be equal.

5. The points of application from which the weights are suspended should be in the same right line perpendicular to the line joining the centres of gravity and of motion.

6. The nearer the right line joining the points of application is to the centre of motion, the larger vibrations of the balance, and a more sensible effect, will be produced.

7. If the centre of motion be situated below the line joining the points of application, the beam, when loaded with equal weights, will overset, rest in any position, or equilibrate according to the weight.

8. When two given weights, suspended from the arms of a balance, are in equilibrio, if these weights when transferred to the opposite scales be still in equilibrio, the arms of the balance are equal.

9. The various adjustments of the balance are these: 1st. Equal weights are readily found, whatever be the state of the

balance; for, if they reduce the beam to the same position, when successively applied to the same arm, they must be equal: then if these equal weights transposed do not disturb the position of the beam, the arms are equal. 2dly. If unequal weights transposed produce equal deflections of the beam, the points of suspension are in the same right lines, perpendicular to that which joins the centre of gravity and motion; and therefore the line joining these points will be horizontal when the beam hangs freely. 3dly. Let the index be directed to any fixed point, then the beam being reversed, if it still pass through the same point, the index is perpendicular to the axis of the beam.

10. The equilibrium of the balance will be effected by the tongue, unless it be continued below the centre of motion, so that the momenta on both sides may be equal and opposite.

11. Minute differences of weight are rendered more discernible by diminishing the friction upon the axis, as by suspending it in a fork with springs, &c.

Indeed when balances are required for accurate philosophical purposes, much caution is requisite in the various parts of the construction, and many peculiar contrivances have been adopted: some of the best of these are given in the following article. Among *domestic* balances the best with which we are acquainted is that of *Brady*.

Hydrostatic BALANCE, is an instrument contrived to determine accurately the specific gravity of both solid and fluid bodies. One of the most ingenious forms of this balance is exhibited in fig. 5. pl. VI. where VCG is the stand or pillar, which is to be fixed in a table. From the top A hangs by two silk strings the horizontal bar BB, from which is suspended by a ring *i* the fine beam of a balance *b*: which is prevented from descending too low on either side by the gently springing piece *txyz*, fixed on the support M. The harness is annulated at *o*, to show distinctly the perpendicular position of the examen, by the small pointed index fixed above it.

The strings by which the balance is suspended, passing over two pulleys, one on each side the piece at A, go down to the bottom on the other side, and are hung over the hook at *v*; which hook, by means of a screw P, is moveable to about the distance of an inch and a quarter backward and forward, and therefore the balance may be raised or depressed so much. But if a greater elevation or depression be required, the sliding piece which carries the screw P, is readily removed to any part of the square brass rod VK, and fixed by means of a screw.

The motion of the balance being thus adjusted, the rest of the apparatus is as follows: HH is a small board fixed upon the piece D, under the scales *d* and *e*, and is moveable up and down in a low slit in the pillar above C, and fastened at any part by a

screw behind. From the point in the middle of the bottom of each scale hangs, by a fine hook, a brass wire *ad*, and *ac*: these pass through holes *m, m*, in the table. To the wire *ad* is suspended a curious cylindric wire *rs*, perforated at each end for that purpose: this wire *rs* is covered with paper graduated by equal divisions, and is about five inches long.

In the corner of the board at E is fixed a brass tube, on which a round wire *hl* is so adapted as to move neither too tight nor too freely, by its flat head I. Upon the lower part of this moves another tube Q, which has sufficient friction to make it remain in any position required: to this is fixed an index T, moving horizontally when the wire *hl* is turned about, and may therefore be easily set to the graduated wire *rs*. From the lower end of the wire *rs* hangs a weight L; and from that a wire *pn*, with a small brass ball *g* about one-fourth of an inch diameter. On the other side from the wire *ac* hangs a large glass bubble, R, by a horse-hair.

Now let us suppose the weight L taken away, and the wire *pn* suspended from *s*: and on the other side let the bubble R be taken away, and a weight, as F, suspended at *c* in its room. This weight F we suppose to be sufficient to keep the several parts hanging from the other scale in equilibrio; at the same time that the middle point of the wire *pn* is at the surface of the water in the vessel O. The wire *pn* is to be of such a size that the length of one inch shall weigh four grains.

Now it is evident, since brass is about eight times heavier than water, that for every inch the wire sinks in the water, it will become half a grain lighter; and half a grain heavier for every inch it rises out of the water: consequently, by sinking two inches below the middle point, or rising two inches above it, the wire will become in effect one grain lighter or heavier. If, therefore, when the middle point is at the surface of the water in equilibrio, the index T be set to the middle point of the graduated wire *rs*, and the distance of *r* and of *s* from the index be each reckoned to contain 100 equal parts; then, if in weighing bodies the weight is required to the hundredth part of a grain, it may be easily obtained by proceeding thus:—Let the body to be weighed be placed in the scale *e*; and let this be so determined that one grain more shall be too much, and one grain less too little. Then the balance being moved gently up or down by the screw P till the equilibrium be nicely shown at *o*, if the index T be at the middle point of the wire *rs*, it shows that the weights put into the scale *e* are just equal to the weight of the body.

But if the index T stand nearer to *r* than to *s*, as suppose 36 of the 100 parts, it shows the number of grains in the scale *e*

were less than equal to the weight of the body in scale *d*, by 36 hundredths of a grain: and if, on the other hand, the index had stood at the division 36 below the middle point of *rs*, then would the grains in the scale *e* indicate more than the real weight in *d* by 36 hundredths of a grain.

Instead of putting the body in the scale *d* as before, let it be appended with the weight F at the hook *c* by a horse-hair, as at R, supposing the vessel of water were away; then observe the equilibrium, and as it hangs, let it be immersed in the water of the vessel o, and it will become much lighter; the number of grains and parts of grains, determined as before, required to restore the equilibrium, will show the weight of water equal in bulk to the body immersed.

In practice, the wire *pn* should be oiled, and then wiped as clean as possible; enough will remain to prevent the water adhering to it. The balance ought to be raised very gently, and when brought to an equilibrium should be gently agitated, to see whether it will return to the equilibrium again.

For the description of M. Paul's accurate steelyard to answer the same purposes, see the article STEELYARD.

M. Prony, of whom we often have had occasion to speak, has invented a stand or support for balances of all dimensions, which is calculated to render the operations for which these instruments are used more expeditious and convenient, without diminishing their accuracy.

" Several experiments," says he, " in which I was engaged during the course of the last winter, put me under the necessity of contriving a support which might be applied promiscuously to every kind of balance, whether provided with a suspending handle or not, and which, without detriment to its accuracy, should afford me commodious means of successively raising and lowering it. It is well known how embarrassing and laborious the operation of weighing is, when performed with balances supported by the hand; though this is often only the smallest inconvenience with which their use is attended.

" Various artists have contrived supports, commodious in their use, and ingenious in their principle; but as each of these supports can only be adapted to a single balance, they become so expensive as to be out of the reach of the majority of artists and experimentalists. I think, therefore, I shall do them an acceptable service by publishing, in compliance with the request of several eminent chemists, the description of a support, which, besides the advantage of being adapted for all kinds of balances, possesses that of being constructed, at a small expense, either in wood or metal.

" A triangular foot of brass A*a*, *a*, *a* (figs. 1. and 2. pl. VI.

representing the elevation and section of my apparatus) has its three extremities *a*, *a*, *a*, firmly screwed down upon a table or horizontal plane. Into the part A of this foot is screwed a cylindrical rod AB, which may be of any arbitrary length: it may even be convenient to have two of these of different lengths, in order that they may be changed, when we wish to employ the machine for very large balances. Those which I have made use of are, the one half a metre, and the other one metre (39·4 inches) in length.

"A vertical pulley, P, is placed at the top of the stem AB, in such a manner that the same vertical plane passes through the axis of the rod, and through the horizontal axis of the pulley; the block or collar CD of this pulley has at its lower part a tube CB, into which enters, with a gentle friction, the superior extremity of the rod AB; a screw, E, serves to keep the pulley in a fixed position.

"Another pulley, P, is fixed at the bottom of the rod AB, in such a position that the tangent of the pulleys P and P is parallel to the axis of the rod AB.

"A cord K*tp*HGPF, to the end of which is suspended on the outside of the vertical table K a small weight *k*, passes through a hole *t* made in the foot *a*, rolls over the pulleys *p* and P, and is attached at F to a piece mm^1nq, which has the form of a fork, and to which are suspended (as I shall shortly explain) the balance, the weights, and the substances that are to be weighed. F*m* is a button, which being screwed at the top of the fork, receives the end of the cord, and by means of a knot made on it sustains the fork.

"The tail or handle of this fork is of a prismatic form at the part m^1n; this prismatic part enters a groove *ff* made at the extremity N of the horizontal piece NO, so that it can slide freely in this groove either upwards or downwards, its course being however limited at m^1, where it is stopped by the enlarged handle of the fork, and at *n* by the greater width produced by the separation of the two branches of the fork.

"The piece NO, which is hollow, and intersected at O by the stem AB, can slide along and turn round this stem: when it is brought to its proper height, it is secured by means of the screw V, and it is then necessary, first, that it should be at such a height that, when the stop *m* rests on the side of the groove *ff*, or when NO can move no further down, the scale of the balance shall be in contact with the table or horizontal plane, in order that we may afterwards be able to raise it the whole height of *fn*; secondly, that the cord FF be in one and the same vertical plane with HG.

"The groove at N ought to be situated in such a manner that

the axis of the prismatic part of the tail of the fork, and the cord FF¹, shall always be in the same vertical plane, or in a parallel line with the axis of the stem AB.

"These dispositions being made, let us imagine the two branches *nq* of the fork to be perforated with holes of different diameters, in order to receive horizontal pins (*gg*) of different sizes; and we shall have all that is requisite for the ordinary operations of weighing, performed in the air with balances, the beams of which are suspended from above.

"In fact, whatever kind of balance we use, we are to introduce the extremity of its suspending handle into the fork *nq*, and insert into the round hole, which the handle of the balance always has at its superior extremity, any one of the pins that will enter with ease; we then apply the piece ON in such a manner as to fulfil the conditions above laid down for the position of this piece; after which, it is to be fixed by the screw V. This being done, the scales of the balance are to be charged, which being in contact with the table, or horizontal plane, can have no motion. When the scales are charged, we lay hold of the small ball *k*, and draw the cord which suspends it so as to raise the balance very slowly: if the scales be not in equilibrio, the cord is to be loosened till they rest again upon the table, and so successively.

"A counterpoise, Q, suspended to the cord FG, ought to preserve the equilibrium with the weight of the balance. By means of this precaution it comes to pass, that the common centre of gravity of all the forces supported by the pulley P, falls in all cases upon the axis of the stem AB, which thus has no tendency to bend.

"If we wish now to use a hydrostatic balance, we adapt to the stem AB a small board ON, fig. 3, which, by means of a cylindrical hole at O, may slide along the rod AB, and be fixed at any arbitrary height by a screw at V. Another piece, or board K^1K^1, is placed upon V^1N^1, in such a manner that the holes TT correspond with the centre of the scales, under which are placed the hooks intended for holding the substances suspended in the water, and K^1K^1 is fixed upon V^1N^1 by means of screws V^1.

"These arrangements being made, let the piece N^1O^1 and the board K^1K^1 be placed in such a manner that, first, the whole height of the balance be placed between this piece and the board, and that the scales LL be in contact with the board K^1K^1, their centres corresponding with holes made in TT. Secondly, that K^1K^1 be sufficiently elevated to enable us to place under it the vessels WW, filled with water, and conveniently

to immerse, in one of these vessels, the substances which we wish to weigh hydrostatically.

"According to the common practice, these substances are suspended by a very thin wire; but by placing, after my method, two vessels, and suspending to the two scales wires of equal diameter, the one of which supports the substance that is to be weighed, and the other merely in part immersed, the magnitude of the diameter will have no influence upon the accuracy of the operation; for, let us suppose the apparatus to be adjusted in such a manner that at first the two wires were in equilibrio with each other (which may easily be obtained by varying the height of the water in the vessels), these two wires will still be in equilibrio, when the beam FF^1 being elevated, will remain in its horizontal position: whence it follows that if one of the wires have suspended from it a substance immersed in the water, and we place in the opposite scale, and consequently out of the water, a weight adequate to keep the equilibrium with the immersed substance, for a horizontal position of the beam, the equilibrium will still be maintained, whatever may be the elevation or depression of the beam, provided it continue in a horizontal position; for the lengths of the wires, either above or below the surface of the water, being equal, the difference between the specific weight of the water and that of the metal will operate equally upon both extremities of the beam. It is evident that this advantage will not be obtained if we employ only the wire to which the substance is suspended, and that the equilibrium, established for a certain elevation and a horizontal position of the beam, will not apply to other elevations of the beam by preserving it in the horizontal position.

"It is to be remarked, that my method compensates not only for the excess of the specific weight of the wires over that of the water, but also for that which depends upon the adhesion of the fluid to the wires, and the covering of water which they carry along with them.

"All that has been said hitherto applies only to balances that are provided with suspended handles; but, in order to render this support absolutely universal in its use, it was necessary that it should be possible to adapt it to a beam which had nothing but its centres; for which purpose I contrived an apparatus, which is suspended, like those of a common balance, to the fork *nq*, and which may receive the centres of any beam. The engraved plates of my machine represent it provided with this apparatus, the construction of which is as follows.

"A piece ss^1 has a screwed hole bored into it at s^1, into which the screw *dd* is inserted half its length. Another hole, made

at *s*, in a perpendicular direction to the first, receives the pin *gg*, to which all the inferior apparatus is suspended. This hole *s* supplies the place of that which is found at the upper extremity of the suspended handle of balances.

"The two other vertical pieces *r*, *r*, fig. 4. have at their upper part cylindrical holes not screwed, in which the screw *dd* can turn freely. These superior parts are placed at an arbitrary distance, and retained in their situation by means of four nut-screws *u*, *u*, *u*, *u*, each of the pieces being fastened between two of these nut-screws. A cylindrical rod *hh* traverses the inferior parts of these pieces *rr*, and is fixed there by means of nut-screws, in such a manner that the superior and inferior points of the piece *rr* are invariably at the same distance.

"Each of these pieces *rr* has, upon the surface which is perpendicular to the direction of *dd* and *hh*, a groove *ee*, and a circular aperture x, having at its lower part a small bracket of polished steel *aa*, intended to support one of the centres of the beam. Into the upper part of the grooves *ee* a rule e^1e^1 is introduced, which must enter with tightness, and which, with the pieces *dd* and *hh*, give such a solidity to the apparatus, that the adjustment of its parts cannot be in the smallest degree deranged. The remainder of the groove, which is not occupied by e^1e^1, ought to be of a length somewhat greater than that of the largest cock or index adapted to the beams which we shall have to use.

"The method of using the apparatus which I have just described is very simple. The beam which we intended to employ is placed between the two branches *rr*; which are removed from each other till the centres can be brought opposite to the circular holes x; the pieces *r*, *r*, are then brought together in such a manner that the centres enter these holes x, and so as still to leave some room for motion between these pieces and the body of the beam, in order that the oscillations of the balance may be perfectly free. The pieces *r*, *r*, are brought parallel with each other, and the adjustment of the apparatus is rendered perfectly firm, by means of nut-screws, by the small cylindrical rod *hh*, and by the rule e^1e^1. The apparatus being adjusted in this manner, it is suspended to the fork *nq*, by inserting the pin *gg* into the hole *s*, and the balance is used in the manner that has already been explained. We know the equilibrium to be established, and the beam to be horizontal, when the index *yy* divides the breadth of the space *ee* into two equal parts; but in order to ascertain the circumstance with greater accuracy, I have attached to the rule e^1e^1 a plummet e^1i^1, by means of which we may distinguish the slightest deviations of the index from the perpendicular direction."

Dr. Coates, of Philadelphia, has proposed a *Hydrostatic Steelyard*, an account of which is given under the head of *Specific Gravity*, in my COMMON PLACE BOOK.

Danish BALANCE, is a kind of balance or steelyard in common use in many parts of the continent of Europe, and is of a very simple construction. It is thus described in the *Encyclopædia Britannica* (art. *Steelyard*): "It consists of a batten of hard wood, having a heavy lump K (fig. 7. pl. VI.) at one end, and a swivel hook *b* at the other. The goods to be weighed are suspended on the hook, and the whole is carried in a loop of whipcord F, in which it is slid backward and forward till the goods are balanced by the weight of the other end. The weight of the goods is estimated by the loop, on a scale of divisions in harmonic progression. They are marked (we presume) by trial with known weights."

It would seem, then, that the writer of the article, whence the above is extracted, was not aware that the divisions on the Danish balance might be effected by a method purely geometrical: yet M. *Roemer* pointed out such a method more than a century ago, in *Recueil des Machines appr. par l'Acad. Roy. Sci.* tom. 1. p. 80. It is in substance as follows: Let AC (figs. 7. 8.) be the distance between the point A from which the body whose weight is to be determined is suspended, and C the centre of gravity of the balance when the weight W is not attached to it. From the point C draw an indefinite line CD, making any angle ACD with the line AC on which the divisions of the balance are to be marked; and through A draw another right line AN parallel to CD. Set off any equal distances CE, EF, FG, GH, HI, &c. along the line CD; and upon AN set off the distance AB equal to one of the equal distances, as CE, upon CD. From B as a fixed point draw lines BE, BF, BG, BH, &c. to the several points of division on CD; and they will intersect the line AC, in the points 1, 2, 3, 4, 5, &c. where the subdivision marks ought to stand in the balance, fig. 7. The numbers 1, 2, 3, 4, &c. fig. 8. denote so many times the actual weight of the balance and its knobs, independent of the adventitious weight W. Thus if the unloaded balance weigh 6lbs. the distances marked 1, 2, 3, 4, 5, &c. in fig. 8. would correspond to the subdivision marks 6, 12, 18, 24, 30, &c. in fig. 7.

M. Roemer has not demonstrated the truth of this construction: but it may be easily shown thus: Let *w* be the weight of the balance and knob, and W that of the body which is to be ascertained by the instrument. Then, when the point of suspension is that marked 1, fig. 8. we have in the triangles AB1, 1CE, the sides AB and CE equal, also angle BA1 = 1CE, and B1A = E1C; therefore these triangles are both equiangular and

equilateral; consequently, $A1 = 1C$, and by the natures of the lever, and the centre of gravity, $W = w$. Again, in like manner when the point of suspension is 2, the triangles $AB2$, $2CF$, are equiangular; and since $FC = 2AB$, we have $C2 = 2A2$, and $W = 2w$. So also the triangles $AB3$, $3CG$, are equiangular; whence because $CG = 3AB$, $C3 = 3A3$, and $W = 3w$; and so on, through the whole division.

This balance has been described more on account of its curiosity than actual utility: for in ascertaining large weights it would be extremely cumbersome and difficult to manage. In the determination of weights not exceeding twenty or thirty pounds, it might, however, be rendered very manageable: for it might be about the length of an exciseman's rod, or a walking-stick, having a knob of lead at one end; and in this case the divisions near the knob might be so numerous as to enable a person to weigh accurately to quarters of pounds, if not to ounces: the rod might be moved to and fro upon a chair-back, or the edge of a trussel; and thus this instrument might often be more conveniently used than a spring steelyard.

BALANCE *of a Clock or Watch*, is that part which by its motion regulates and determines the beats. The circular part of it is called the *rim*, and its spindle the *verge;* there belong to it also two pallets or nuts, that play in the fangs of the crown-wheel: in pocket watches that strong stud in which the lower pivot of the verge plays, and in the middle of which one pivot of the crown-wheel runs, is called the *potence:* the wrought piece which covers the balance, and in which the upper pivot of the balance plays, is the *cock;* and the small spring in the new pocket watches is called the *regulator*.

The motion of a balance, as well as that of a pendulum, being reciprocating, while the pressure of the wheels is constantly in one direction, it is obvious that some art must be used to accommodate the one to the other. When a tooth of the wheel has given the balance a motion in one direction, it must quit it, that it may get an impulsion in the opposite direction. The balance or pendulum thus escaping from the tooth of the wheel, or the tooth escaping from the balance, has given to the general construction the name of scapement among our artists. See SCAPEMENT.

Some of the most important propositions relative to watch balances may be concisely stated as follows: 1. The balance of a watch is analogous to the pendulum, in its properties and use. The simple balance is a circular annulus, equally heavy in all its parts, and concentrical with the pivots of the axis on which it is mounted. This balance is moved by a spiral spring called the balance spring, the invention of Mr. Hook.

2. The pendulum requires a less maintaining power than the balance. Hence the natural isochronism of the pendulum is less disturbed by the relatively small inequalities of the maintaining power.

3. The elastic force of the spring which impels the circumference of the balance is directly as the tension of the spring; that is, the weights necessary to counterpoise a spiral spring's elastic force, when the balance is wound to different distances from the quiescent point, are in the direct ratio of the arcs through which it is wound.

4. The vibrations of a balance, whether through great or small arcs, are performed in the same time. For the accelerating force is directly as the distance from the point of quiescence: hence, therefore, the motion of the balance is analogous to that of a pendulum vibrating in cycloidal arches (vol. i. art. 276).

5. The time of the vibration of a balance is the same as if a quantity of matter, whose inertia is equal to that by which the mass contained in the balance opposes the communication of motion to the circumference, described a cycloid whose length is equal to the arc of vibration, described by the circumference, the accelerating force being equal to that of the balance.

6. The times of vibration of different balances are in a ratio compounded of the direct subduplicate ratios of their weights and semidiameters, and the inverse subduplicate ratio of the tensions of the springs, or of the weights which counterpoise them, when wound through a given angle.

7. The times of vibration of different balances are in a ratio compounded of the direct simple ratio of the radii and direct subduplicate ratio of their weights, and the inverse subduplicate ratio of the absolute forces of the springs at a given tension.

8. Hence the absolute force of the balance spring, the diameter and weight of the balance being the same, is inversely as the square of the time of one vibration.

9. The absolute force or strength of the balance spring, the time of one vibration, and the weight of the balance being the same, is inversely as the square of the diameter.

10. The weight of the balance, the strength of the spring, and time of vibration being the same, is inversely as the square of the diameter.

Hence, a large balance, vibrating in the same time with the same spring, will be much lighter than a small one.

11. If the rim of the balance be always of the same breadth and thickness, so that the weight shall be as the radius, the strength of the spring must be as the cube of the diameter

of the balance, that the time of vibration may continue the same.

12. The momentum of the balance is increased better by increasing its diameter than its weight.

13. The longer a detached balance continues its motion the better.

14. The greater the number of vibrations performed by a balance in a given time, the less susceptible is it of external agitations.

15. Slow vibrations are, to a certain extent, preferable to quick vibrations: but there is manifestly a limit; for if the vibrations be too slow, the watch will be liable to stop.

16. A balance should describe as large arches as possible, as suppose 240°, 260°, 300°, or an entire circle.

First, because the momentum of the balance is thus increased; and therefore the inequalities in the force of the maintaining power bear a less proportion to it, and of consequence will have less influence. 2dly. The balance is less susceptible of external agitations. 3dly. A given variation in the extent of the vibrations produces a less variation in the going of the machine.

But care must be taken that in these great vibrations, the spring shall neither touch any obstacle, nor its spires touch each other in contracting.

17. The time of the vibration of the balance is increased by heat, and diminished by cold. First, because the length of the spiral spring is increased by heat, and therefore its force diminished; and the contrary by cold. 2dly. The diameter of the balance is increased by heat, and therefore also the time of vibration; and the contrary by cold.

18. That balance is the most perfect which, without the compensation of a thermometer, is most subject to the influence of heat and cold. Because the obstructions from oil and friction act as a compensation to the expansion or contraction of the spring and balance; therefore that balance which is most affected is most free from the influence of oil and friction.

19. The errors in the going of a watch, arising from the change of temperature, may be corrected by varying the length of the balance spring. Nevertheless, as it is extremely difficult to form an isochronal spiral, any variation in its length is dangerous, because we shall thus probably lose that point which determines its isochronism.

20. The errors in the going of a watch, occasioned by the variation of temperature, may be corrected by varying the diameter of the balance.

This may be effected by a peculiar contrivance which has obtained the name of the *expansion balance,* being composed

of two different metals which possess different degrees of expansibility, as brass and steel, for instance; of which two metals it has been observed, that the increase of dimensions by expansion, in like elevations of temperature, is nearly as 2 to 1. For, according to Mr. Smeaton's experiments (vol. 48, Phil. Trans.), the corresponding expansions of hard steel and brass-wire are as 147 and 232, the expansions being occasioned by a change from a medium temperature to that of 180° of Fahrenheit's thermometer. One of the most approved constructions of an expansion balance is exhibited in plate VII. and is thus described by Mr. Nicholson: The outer part of the rim is brass, and the inner steel. After this compound rim is brought to its figure by turning, it is cut through in three places A, B, C, which sets one end of each third part of the periphery at liberty to move outwards, when the temperature is diminished, or inwards when it is increased. D, E, F, are three similar and equal masses of metal, fitted upon the circular bars in a proper manner to admit of their being fixed at any required distance from the extremity, where the motion is most considerable. G, H, I, are three screws, the heads of which may be set nearer to, or further from, the centre, and serve as weights to effect the adjustments for position and rate. The peculiar advantage of this balance may be explained as follows: when an increase of heat diminishes the elastic force of the pendulum spring K, the outer brass rim being lengthened more than the steel, must throw the weights D, E, F, nearer to the axis, and diminish the effect of the inertia of the balance, which consequently is as speedily carried through its vibration as before. And on the contrary, when cold weather adds to the elastic force of the spring, the same weights are also thrown further out, and prevent the acceleration which would have followed. The exact adjustment of the weights is found by trial of the going of the machine: if it gain by heat, the weights do more than compensate, and must be moved further from the extreme ends of the circular compound bars; but if the gain be produced by cold, the spring predominates, and the weights will accordingly require to be set further out.

BALLISTIC PENDULUM, an obvious, though very ingenious contrivance, first proposed by Mr. Benjamin Robins, for the purpose of ascertaining the velocity of a cannon-ball. The contrivance depends upon the principle explained art. 313 of our first volume:—The block of wood which is struck by the ball, instead of being left at liberty to move straight forward in the direction of the ball's motion, is suspended like the weight of the vibrating pendulum of a clock, by a strong iron stem (with adequate braces) having a horizontal axis at the top, on

the ends of which it vibrates freely when struck by the ball. This large pendulum, after receiving the blow, is penetrated by the ball to a small depth, and by reason of the motion communicated to it, oscillates round its axis, describing an arch, which is greater or less according to the magnitude of the impulsion. From the extent of the arch described by the vibrating pendulum, the velocity of any point of the block can be readily computed: for, from the extent of the arch and the radius of description, the versed sine becomes known; and it is well known that the velocity with which the body that describes such an arch commences its motion, is the same as the velocity which would be required to carry the body vertically through the versed sine before its whole motion becomes destroyed by gravity. This velocity, referred to the centre of oscillation of the pendulum, will be to the velocity communicated by the ball to the block as the distance of the centre of oscillation from the axis of suspension, to the distance of the point of impact from the same: and hence the velocity of the ball becomes inferred, from the consideration that it and the pendulum have velocities inversely as their masses. Thus, the determination of the very great velocity of the ball, is made to flow from the measurement of the arch described by the pendulum in consequence of the blow struck.

Several blocks of this kind, varying in weight from 600 lbs. up to about 25 cwt., were constructed and employed under the direction of Dr. Hutton, for the purpose of ascertaining the initial velocities, as well as the velocities at different distances from the mouth of the piece, of balls weighing from 1 to 6 pounds. The minutiæ of the construction, the requisite investigations, the practical methods of determining the centres of gravity and oscillation, and the arch of vibration, as well as the ample detail of the doctor's most valuable collection of experiments, may be seen in the 2d and 3d vols. of his "Tracts," published in 1812.

In 1815 a ballistic pendulum weighing 7000 lbs. and serving for experiments upon the velocities of balls propelled from 9, 12, and even 24 pounders, was constructed in the Royal Arsenal, Woolwich: the frame work for the apparatus is built into the wall of a suitable edifice, in order to ensure accuracy and stability. The experiments with an apparatus of this magnitude have already presented some curious and important results.

BARK-MILL, a mill constructed for the purpose of grinding and preparing bark, till it is fit for the use of a tanner.

Bark-mills, like most other mills, are worked sometimes by means of horses, at others by water, and at others by wind.

One of the best mills we have seen described for these purposes is that invented by Mr. Bagnall of Worsley in Lancashire: this machine will serve not only to chop bark, to grind, to riddle and pound it; but to beam, or work green hides and skins out of the mastering or drench, and make them ready for the ouse or bark liquor; to beam sheepskins and other skins for the skinner's use; and to scour and take off the bloom from tanned leather, when in the currying state. The nature and connexion of the different parts of this contrivance may be understood from the three figures on the right-hand side of plate VII. together with the following description.

Fig. 1. is a horizontal plan of the mill. Fig. 2. longitudinal section of it. Fig. 3. transverse section of it.

A, The water-wheel, by which the whole machinery is worked.

B, The shafts.

C, The pit-wheel, which is fixed on the water-wheel shaft B, and turns the upright shaft E, by the wheel F, and works the cutters and hammer by tapets.

D, The spur and bevil-wheel at the top of upright shafts.

E, The upright shaft.

F, The crown-wheel, which works in the pit-wheel C.

G, The spur-nut to turn the stones I.

P, The beam, with knives or cutters fixed at the end to chop or cut the bark; which bark is to be put upon the cutters or grating *i*, on which the beam is to fall.

Q, The tryal that receives the bark from the cutters *i*, and conveys it into the hopper H, by which it descends through the shoe J to the stones I, where it is ground.

K, The spout, which receives the bark from the stones, and conveys it into the tryal L; which tryal is wired, to sift or dress the bark as it descends from the stones I.

M, The trough to receive the bark that passes through the tryal L.

R, The hammer, to crush or bruise the bark that falls into the dish S, which said dish is on the incline, so that the hammer keeps forcing it out of the lower side of the said dish, when bruised.

k, A trough to receive the dust and moss that passes through the tryal Q.

T, The bevil-wheel, that works in the wheel D, which works the beam-knife by a crank V at the end of the shaft *u*.

W, The penetrating rod, which leads from the crank V to the start *x*.

x, The start, which has several holes in it to lengthen or shorten the stroke of the beam-knife.

y, The shaft, to which the slide rods *h*, *h*, are fixed by the starts *n*, *n*.

h, The slide rod, on which the knife *f* is fixed; which knife is to work the hides, &c. On the knife are two springs *a*, *a*, to let it have a little play as it makes its stroke backwards and forwards, so that it may not scratch or damage the hides, &c.

z, Is a catch in slide-rod *h*, which catches on the arch-head *e*; and the said arch-head conveys the knife back without touching the hide, and then falls back to receive the catch again.

l, The roller to take up the slide-rod *h*, while the hides are shifting on the beam *b* by pulling at the handle *m*.

b, The beam to work the hides, &c. on. Each beam has four wheels *p*, *p*, working in a trough road *g*, *g*, and removed by the levers *c*, *c*. When the knife has worked the hide, &c. sufficiently in one part, the beam is then shifted by the lever *c* as far as is wanted.

d, A press, at the upper end of the beam, to hold the hide fast on the beam while working.

e, An arch-head, on which the slide-rod *h* catches.

f, The knife fixed on the slide-rod *h*, to work the hides, &c.

i, Cutters or grating to receive the bark for chopping.

The beam P, with knives or cutters, may either be worked by tapers, as described, or by the bevil-wheel T, with a crank, as V, to cut the same as shears.

The knife *f* is fixed at the bottom of the start, which is fixed on the slide rod *h*; the bottom of the start is split open to admit the knife, the width of one foot; the knife should have a gudgeon at each end, to fix in the open part of the start; and the two springs *a*, *a*, prevent the knife from giving too much way when working; the knife should be one foot long and four or five inches broad.

The arch-head *e* will shift nearer to, or further from, the beam *h*, and will be fixed so as to carry the knife back as far as is wanted, or it may be taken away till wanted.

The roller *l* is taken up by pulling at the handle *m*, which takes up the slide-rod so high as to give head-room under the beam-knife. The handle may be hung upon a hook for that purpose. The slide-rod will keep running upon the roller all the time the hide is shifting; and when the hide is fixed, the knife is put on the beam again by letting it down by the handle *m*. There may be two or more knives at work on one beam at the same time, by having different slide-rods. There should be two beams, so that the workmen could be shifting one hide, &c. while the other was working. The beam must be flat, and a little on the slope. As to the breadth, it does not signify; the broader it is the less shifting of the hides will be wanted, as the

lever *c* will shift them as far as the width of the hide, if required. Mr. Bagnall has formed a kind of press *d*, to let down, by a lever, to hold the hide fast on each side of the knife if required, so that it will suffer the knife to make its back stroke without pulling the hide up as it comes back. The slide-rod may be weighted, to cause the knife to lay stress on the hide, &c. according to the kind and condition of the goods to be worked.

Hides and skins for the skinner's use are worked in the same way as for the tanners.

Scouring of tanned leather for the currier's use will be done on the beam, the same as working green hides. It is only taking the knife away, and fixing a stone in the same manner as the knife by the said joint, and to have a brush fixed to go either before or after the stone. The leather will be better secured this way than by hand, and much sooner.

The whole machinery may be worked by water, wind, steam, or any other power. And that part of the machinery which relates to the beaming part of the hides may be fixed to any horse-bark-mill, or may be worked by a horse or other power separately.

BARKER'S MILL is a kind of water-mill, invented by Dr. Barker, which without either wheel or trundle performs the operation of grinding corn. This mill is represented in fig. 3. pl. IV. in which A is a pipe or channel that brings water from a reservoir to the upright tube. The water runs down the tube, and thence into the horizontal trunk C, which has equal arms; and, lastly, runs out through holes at *d* and *e*, opening on contrary sides near the ends of those arms. These orifices *d*, *e*, have sliders fitted to them, so that their magnitude may be increased or diminished at pleasure.

The upright spindle D is fixt in the bottom of the trunk, and screwed to it below by the nut *g*; and is fixt into the trunk by two cross bars at *f*: so that, if the tube B and trunk C be turned round, the spindle D will be turned also.

The top of the spindle goes square into the rynd of the upper mill-stone H, as in common mills; and as the trunk, tube, and spindle turn round, the mill-stone is turned round thereby. The lower or quiescent mill-stone is represented by I; and K is the floor on which it rests, in which is the hole L to let the meal run through, and fall down into a trough which may be about M. The hoop or case that goes round the mill-stone rests on the floor K, and supports the hopper, in the common way. The lower end of the spindle turns in a hole in the bridge-tree GF, which supports the mill-stone, tube, spindle, and trunk. This tree is moveable on a pin at *h*, and its other end is supported by an iron rod N fixed into it, the top of the rod going through

the first bracket O, and having a screw-nut o upon it, above the bracket. By turning this nut forward or backward, the mill-stone is raised or lowered at pleasure.

Whilst the tube B is kept full of water from the pipe A, and the water continues to run out from the ends of the trunk, the upper mill-stone H, together with the trunk, tube, and spindle, turn round. But if the holes in the trunk were stopt, no motion would ensue; even though the tube and trunk were full of water. For, if there were no hole in the trunk, the pressure of the water would be equal against all parts of its sides within. But when the water has free egress through the holes, its pressure there is entirely removed: and the pressure against the parts of the sides which are opposite to the holes turns the machine.

Mr. James Rumsey, an American gentleman, has rather improved this machine, by conveying the water from the reservoir, not by a pipe as ADB, in great part of which the spindle turns, but by a pipe which descends from A, without the frame LN, till it reaches as low, or lower, than G; and then to be conveyed by a curvilinear neck and collar from G to g, where it enters the arms, as is shown by the dotted lines at the lower part of the figure. A like improvement was made by M. Segner, a German.

Most of the authors who have attempted to lay down the theory of this mill have fallen into error: the most ingenious theory we have yet seen is by Mr. *Wm. Waring*, (given in the *American Transactions*, vol. iii.); which, with some such corrections as appeared necessary to adapt his rules to practical purposes, is nearly as follows:

1. The first inquiry relates to the *magnitude of the pipe* which conveys the water from the reservoir to the centre of the horizontal tube ed, at g. To this end, let A=the area of the orifice by which the water is admitted at g; h=the perpendicular height of the surface of the water in the reservoir above g; d=the vertical depth of any horizontal section of the pipe below the same surface; s=the surface or area of the horizontal section of the pipe, at the depth d. Then since the areas in the several parts of the pipe should be inversely as the velocities, and the velocities (art. 439, cor. 2. vol. I.) are in the subduplicate ratio of the depths below the head, those areas must be inversely in the subduplicate ratio of the depths; consequently, $\frac{s}{A}=\frac{\sqrt{h}}{\sqrt{d}}$, and $s=A\sqrt{\frac{h}{d}}$. So that the pipe must have its bore increased from the level of g upwards in the ratio of 1 to $\sqrt{\frac{h}{d}}$; and if a section in any part be less than would

be assigned by this ratio, the water will be obstructed in its passage.

2. *Of the initial force with which the machine commences its motion.* If we conceive the water pressing in the tube from g towards e, previous to the opening of the aperture, there will manifestly be no motion occasioned; because the forces on the opposite sides of the tube balance each other, and the force against the end C is resisted by the fixed axle Dg, or if we consider both arms, it is balanced by the equal force acting upon the equal end at d, in an opposite direction. But if one of the apertures, as d (its area being $=a$), is opened, the pressure upon that portion of the tube is taken away, and the equal and opposite pressure upon an equal portion of the contrary side of the tube, having now nothing to keep it in equilibrio, tends to move the arm Cg about the axis Dg: in like manner when the aperture e (also $=a$) is opened, the pressure which was previously counterbalanced by the opposite pressure on the orifice e, now exerts its tendency to produce a rotatory motion about the axis Dg: so that, combining together the effects of both these unbalanced pressures, and considering that the pressure of water upon any point is proportional to the depth of that point below the upper surface of the fluid, we shall have $2ahw$, for the force which causes the rotatory motion to commence; the values of a and h being taken in feet, and w representing $62\frac{1}{2}$ lbs. avoirdupois, the weight of a cubic foot of water. But as the velocity of rotation increases, the pressure depending upon the relative velocities of the water and the sides of the tube diminishes, and consequently the power is diminished, notwithstanding what is gained by that which we now proceed to consider.

3. *The centrifugal force.* This may be found in a similar manner to that which was adopted when considering the theory of the centrifugal pump (art. 537, vol. I.). Thus, if besides the preceding notation we take l for the length of each arm gd, ge, t for the time of rotation, g for $32\frac{1}{6}$ feet, the measure of the force of gravity, and π for $3{\cdot}141593$; since a is the section of the flowing water at right angles to its motion, we shall have, by proceeding as in the article just referred to, $\frac{2\pi^2 l^2}{gt^2} =$ the length of a column of water, whose pressure is equal to the centrifugal force, or $\frac{4\pi^2 awl^2}{gt^2} = 76{\cdot}70625\frac{al^2}{t^2}$ the weight of a column of water in lbs., which is equivalent to the centrifugal force of the fluid in both arms. And this is equivalent to the augmentation of power at the apertures, because fluids press equally in all directions.

4. *The inertia of the fluid* greatly counteracts the effects of the centrifugal force. The inertia of the rotatory tube with the contained fluid would not continue to resist the moving power after the velocity became uniform, were the same fluid retained in it as was in it when the motion was first imparted: but as this passes off, and there is a continual succession of new matter acquiring a motion in the direction of the rotation, there must be a constant re-action against the sides of the tube, equal to the communicating force. Now this re-action is very different from that of a fluid confined in the tube, when it begins to move; because a particle at the extremity of the tube is not to receive its whole circular motion there, but gradually acquires it by a uniform acceleration during its passage along the tube: so that we must here inquire what force will give to the quantity of water alw, in the time $\frac{l}{v}$ of its passing through its respective horizontal arm, the velocity $\frac{2\pi r}{t}$, in the direction of the aperture. Managing this according to the rules given for forces in the Dynamics, we shall have $\frac{12\cdot273alv}{t} \times \frac{8\cdot0208}{5} = 19\cdot6878 \frac{alv}{t}$, for the resistance in lbs. opposed to each arm, such resistance being estimated as if accumulated at the distance $\frac{1}{2}l$ from the centre of motion.

5. *Acquired velocity of the water.* According to the theory of Hydraulics, the velocity of water issuing through an aperture at the depth h below the upper surface of a reservoir is expressed by $8\cdot0208 \sqrt{h}$, which, when reduced, in conformity with the experiments of Bossut and others, becomes $5 \sqrt{h}$ very nearly; and this is the velocity of the water passing out of the tubes at the commencement of the rotation. Then, as $\sqrt{(2ahw)} : 5 \sqrt{h} :: \sqrt{(2ahw + 76\cdot70625 \frac{al^2}{t^2})} : 5 \sqrt{(h + 38\cdot35312 \frac{l^2}{wt^2})} = 5 \sqrt{(h + \cdot61365 \frac{l^2}{t^2})} = v$, the acquired velocity of the water.

6. *Ratio of the central force to the inertia.* This will be ascertained by substituting for v in the expression $19\cdot6878 \frac{alv}{t}$ its value just found; so that we have $98\cdot439 \frac{al^2}{t^2} \times \sqrt{(\cdot61365 + \frac{ht^2}{l^2})}$ for the inertia, while the centrifugal force is measured by $76\cdot70625 \frac{al^2}{t^2}$. Now we find that $76\cdot70625 \frac{al^2}{t^2} : 98\cdot439 \frac{al^2}{t^2} \times$

$\surd(\cdot 61365+\frac{ht^2}{l^2})::1:1\cdot 2833\ \surd(\cdot 61365+\frac{ht^2}{l^2})$, or as 1 : $\surd(1+\frac{1\cdot 646ht^2}{l^2})$ very nearly; which is the ratio of the power gained by the centrifugal force to the obstruction arising from inertia. Whence it appears that the latter is greater than the former, except when $t=0$, $h=0$, or $l=\infty$, cases never occurring in practice; and that the longer the arms, the less the fall of water, and the greater the velocity of rotation, the nearer these forces approach to the ratio of equality.

6. *Adjustment of the parts and motion.* Here it must be particularly observed, that the centrifugal force should not exceed the gravity of the water revolving in the arms *gd*, *ge*: for in that case the water would be drawn into the tube faster than it could be naturally supplied at its entrance, by the velocity proper to that depth, and of consequence a vacuum must be occasioned: nor should the velocity of the apertures be greater than half that of the water through them; for the apertures being still adapted in point of magnitude to the velocity, the effluent quantity or number of acting particles is as the time, the momentum is in the simple ratio of the relative velocity, and therefore (art. 472, cor. 3. vol. I.) the greatest effect will be produced when the velocity of the apertures is equal to half that due to the head of water. These two conditions expressed algebraically will furnish the equations,

$$76\cdot 70625\ \frac{al^2}{t^2}=2alw\ \ldots\ \frac{2\pi l}{t}=\tfrac{5}{2}\surd(h+l):$$

from which equations we deduce the following,

$$\text{viz.}\begin{cases} h = 9\cdot 29345l = 15\cdot 1446t^2 \\ l = 1.6296t^2 = \cdot 1076h \\ t = \surd\cdot 61365l = \surd\cdot 06603h. \end{cases}$$

Whence it appears that h, l, and t^2, are nearly in the constant ratio of 15, $9\frac{1}{4}$, and 1.

Still it should be observed that while l and t are preserved in a constant ratio, the values of $76\cdot 70625\frac{al^2}{t^2}$, and of $12\cdot 273\frac{alv}{t}$, i. e. of the central force and of the inertia, must remain the same: so that the brachia may be made of any length at pleasure (not less than $\cdot 1076h$) if the time of revolution be taken in a corresponding proportion, or so that the velocity of the apertures undergo no variation, which will be ensured by making $t=\surd\ 61365l$: for a double or triple radius, revolving in a double or triple time, or with half or a third the angular velocity, has the same absolute velocity at the extremity; and,

with the same power there applied, will produce the same effect. Hence,

7. *The moving force and velocity of the machine, when the effect is a maximum*, may be found. For, if we put $\cdot 61365l$ for t^2, and $9\cdot 29345l$ for h in the expression $\sqrt{(1+\frac{1\cdot 646ht^2}{l^2})}$ it becomes $\sqrt{(1+3)}=2$; in which case the resistance of inertia is just double the central force, or the gravity of the water in the tube$=125al$, which taken from the impelling force leaves $62\cdot 5(ah+l)-125al=62\cdot 5a(h-l)=55\cdot 775ah$ lbs. avoirdupois $=$ the real moving force, at the distance of the centres of the apertures from the centre of motion, l being taken $=\cdot 1076h$. And by a like substitution the velocity $\frac{5}{2}\sqrt{(h+l)}$, becomes $\frac{5}{2}\sqrt{(1\cdot 1076h}=2\cdot 63205\sqrt{h})$ feet per second.

8. *Area of the apertures.* If A $=$ the area of a section of the race perpendicular to the direction of its motion, V $=$ its velocity per second, both in feet, a and h as before; then it will be $AV=10a\sqrt{(h+\cdot 61365\frac{h}{t^2})}$ cubic feet $=$ the quantity of water emitted per second, by both apertures: hence $a=\frac{AV}{14\cdot 2722\sqrt{h}}=\frac{\cdot 070066AV\sqrt{h}}{h}$, the area proper for one of the apertures.

From the preceding investigation we may deduce the following

EASY PRACTICAL RULES.

1. Make each arm of the horizontal tube, from the centre of motion to the centre of the aperture, of any convenient length, not less than $\frac{1}{9}$ of the perpendicular height of the water's surface above these centres.

2. Multiply the length of the arm in feet, by $\cdot 61365$, and take the square root of the product for the proper time of a revolution in seconds; and adapt the other parts of the machinery to this velocity: or,

3. If the time of a revolution be given, multiply the square of this time by $1\cdot 6296$ for the proportional length of the arm in feet.

4. Multiply together the breadth, depth, and velocity, per second of the race, and divide the last product by $14\cdot 27$ times the square root of the height, for the area of either aperture: or, multiply the continual product of the breadth, depth, and velocity, of the race, by the square root of the height, and by the decimal $\cdot 07$; the last product, divided by the height, will give the area of the aperture.

5. Multiply the area of either aperture by the height of the head of water, and the product by 55·775 (or 56lbs.), for the moving force, estimated at the centres of the apertures in pounds avoirdupois.

6. The power and velocity at the apertures may be easily reduced to any part of the machinery, by obvious rules.

BAROMETER, a well-known instrument for measuring the weight or pressure of the atmosphere, and the variations that happen therein, in order to indicate the changes in the weather, or the changes in vertical distance from any point upon the earth's surface.

We shall here describe a few of the most useful constructions of the barometer, and shall begin with

The Common Barometer. This is represented at fig. 1. plate VII. such as it was invented by Torricelli. AB is a glass tube, of $\frac{1}{4}$, or $\frac{1}{3}$, or $\frac{1}{2}$ inch wide, the more the better, and about 34 inches long, being close at the top A, and the open end B immersed in a basin of quicksilver CD, which is the better the wider it is. To fill this, or any other barometer, take a clean new glass tube, of the dimensions as above, and pour into it well-purified quicksilver, with a small funnel either of glass or paper, in a fine continued stream, till it wants about half an inch or an inch of being full; then, stopping it close with the finger, invert it slowly, and the air in the empty part will ascend gradually to the other end, collecting into itself such other small air bubbles as unavoidably get into the tube and mix with the mercury, in filling it with the funnel: and thus continue to invert it several times, turning the two ends alternately upwards, till all the air bubbles are collected, and brought up to the open end of the tube, and till the part filled shall appear, without speck, like a fine polished steel rod. This done, pour a little more quicksilver, to fill the empty part quite full, and so exclude all air from the tube: then, stopping the orifice again with the finger, invert the tube, and immerse the finger and end, thus stopped, into a basin of like purified quicksilver. In this position withdraw the finger; so shall the mercury descend in the tube to some place, as H, between 28 and 31 inches above that in the basin at F, as these are the limits between which it usually stands in this country on the common surface of the earth. Then measure, from the surface of the quicksilver in the basin at F, 28 inches to K, and 31 inches to L, dividing the space between them into inches and tenths, which are marked on a scale placed against the side of the tube; and the tenths are subdivided into hundredth parts of an inch by a sliding index carrying a vernier or nonius. These 3 inches, between 28 and 31, so divided, will answer for all the ordinary purposes

of a stationary or chamber barometer; but for experiments on altitudes and depths it is proper to have the divisions carried on a little higher up, and a great deal lower down. In the proper filling and otherwise fitting up of the barometer, several circumstances are to be carefully noted; as, that the bore of the tube be pretty wide, to allow the freer motion of the quicksilver, without being impeded by an adhesion to the sides; that the basin below it be also tolerably large, in order that the surface of the mercury at F may not sensibly rise or fall with that in the tube; that the bottom of the tube be cut off rather obliquely, so that when it rests on the bottom of the basin there may be a free passage for the quicksilver; and that, to have the quicksilver very pure, it is best to boil it in the tube, which will expel all the air from it. This barometer is commonly fitted up in a neat mahogany case, together with a thermometer and hygrometer.

2. As the scale of variation is small in the common barometer, being not more than 3 inches, several contrivances have been devised to enlarge the scale, or to render the motion of the quicksilver more perceptible. Among the best of these is that known by the name of *Diagonal Barometer*, represented in fig. 2. where ABC is a tube hermetically sealed at C, and immersed in a basin of mercury at A. This tube is perpendicular from A to B, where the scale of variation begins, but is there bent into the form BC, making an acute angle FBC. This part BC extends to the highest limit in the scale of variation, viz. IC; and consequently while the mercury rises from K to I, in the common barometer, it will move in this from B to C, enlarging the scale of variation in the proportion of BC to FB; that is, of the diagonal to the least side of the parallelogram.

But this barometer is attended with one great inconvenience, which lessens its utility. Quicksilver being a very heavy body, and supported on the part BC, forming an inclined plane, it must have a very considerable degree of friction, which will be increased in proportion as the part BC is more oblique; and consequently the very small and nice variation of the air's pressure cannot be so accurately indicated in this as in the common form. It also very often happens, from the inclination of the part BC, that the quicksilver divides into several parts, and thence frequently requires the trouble of re-filling the tube. This barometer was invented by Sir Samuel Moreland.

3. Cassini invented another kind of barometer, in order to enlarge the scale of variation; an invention which was afterwards completed by M. John Bernoulli. It consists of a tube

ACDF (fig. 3.) hermetically sealed at A, and bent to a right angle at D; whence it has acquired the name of the horizontal rectangular barometer. The mercury stands in both the legs from E to B; the scale of variation from A to C is made in a larger part; and it is evident, that in moving three inches from A to C it will move through so many times three inches in the small leg DF as the bore of DF is less than the bore of AC; whence the motion of the mercury at E must be extremely sensible. But the inconvenience here too is, that the mercury is very apt to break off in the leg E, as well as to run out at the end E. Here is also a great degree of friction, and at the same time the attraction of cohesion will, from the smallness of the bore DF, impede the free motion of the mercury.

4. *The Pendant Barometer* is made in another form, consisting of a single tube suspended by a string fastened to the end A (fig. 4.) This tube is of a conical or tapering form, the end A being a *little* less than that at B. It is hermetically sealed at A, and filled with mercury: then will the mercury sink to its common station, and admit a length of altitude CD, the same with that in the common barometers. But, from the conical bore of the tube, the mercury will descend as the air becomes lighter, till it reaches its lowest altitude, when the mercury will stand from the lowest part of the tube B to E; so that BE=28 inches: and consequently the mercury will, in such a tube, move from A to E, or 32 inches, if the tube be five feet long; so that the scale AE may here be made more than 10 times greater than that of the common barometer. The inconvenience attending this barometer is, that as the tube must be made of a very small bore, to prevent the mercury from falling out by an accidental shake, the friction and adhesion to the sides of the tube prevent that freedom of motion necessary to show a very small variation in the weight of the air.

5. Mr. Rowning had several contrivances for enlarging the scale, and that in any proportion whatever. One of these is described in No. 427. Phil. Trans. and has now obtained the name of *Rowning's Barometer:* it is represented at fig. 5. where ABC is a compound tube, hermetically sealed at A, and open at C; empty from A to D, filled with mercury from thence to B, and thence to E with water. Here, by varying the proportions of the two tubes AF and FC, the scale of variation may be changed in any degree.

6. *Dr. Hooke's Wheel Barometer* was invented about 1668, and is likewise intended to render the alterations in the state of the air more perceptible. Here the barometer tube has a large ball AB at the top (fig. 9. pl. VII.), and is bent up at the lower or open end, where an iron ball, G, floats on the top of the

mercury in the tube, to which is connected another ball, H, by a cord, hanging freely over a pulley, turning an index KL about its centre. When the mercury rises in the part FG it raises the ball, and the other ball descends and turns the pulley with the index round a graduated circle from N towards M and P; and the contrary way when the quicksilver and the ball sink in the bent part of the tube. Hence the scale is easily enlarged ten or twelve fold, being increased in proportion as the length of the index exceeds the radius of the pulley. But then the friction of the pulley and axis greatly obstructs the free motion of the quicksilver. Contrivances to lessen the friction are described in Phil. Trans. vol. 52 and 60. In Nicholson's Journal, No. 9. New Series, the Rev. James Wilson has described a method of increasing the sensibility of the barometer, *ad libitum*, which is very ingenious; but need not be inserted here: for this, and all contrivances, having the same end in view, are not superior, but often inferior, to the common barometer, for all philosophical purposes; and that for a reason which admits of no reply. Their scale must be determined in all its parts by that of the common barometer; and, therefore, notwithstanding their great range, they are susceptible of no greater accuracy than that with which the common barometer can be observed and measured. And besides this, these compound barometers have an additional source of error, in the action of cohesion, the operation of friction, &c. So that, except perhaps for mere chamber purposes, the common construction of the barometer, with a nonius applied to its scale, is greatly preferable; and our attention should be entirely directed to its improvement and portability.

7. This leads us to speak of the construction of a *Portable Barometer*, which may be carried from one place to another without being rendered unfit for use; and is, therefore, ready to be adopted at all times in the mensuration of altitudes, &c. In this barometer the end of the tube is tied up in a leathern bag, not quite full of mercury, which being pressed by the air, forces the mercury into the tube, and keeps it suspended at its height. This bag is usually enclosed in a box, through the bottom of which passes a screw, by whose means the mercury may be forced up to the top of the tube, and prevented from breaking it by dashing against the top when the instrument is removed from one station to another. Mr. Patrick was, we believe, the first who made a contrivance of this kind; but the portable barometer has received various improvements since by M. de Luc, Sir Geo. Shuckburgh, Gen. Roy, Mr. Ramsden, and others. Fig. 8. pl. VII. represents this instrument as enclosed in its mahogany case by means of three metallic rings

b, b, b. This case is a hollow cone, so shaped within as steadily to contain the body of the barometer, and is divided into three branches from *a* to *c*, forming three legs or supports for the instrument when observations are making, and sustaining it at the part *g* of the case; by an improved kind of gimbals, as it appears in fig. 6. in which its own weight renders it sufficiently steady at any time. In the part of the frame *ag*, where the barometer tube appears, a long slit or opening is made, so that the column of mercury may be seen against the light, and the vernier piece, *a*, brought down to coincide very nicely with the edge of the mercury. When the instrument is fixed in its stand, the screw *f* is to be turned to let the mercury down to its proper position, and a peg at *p* must be loosened, in order that the external air may be admitted to act upon the mercury contained in the box *b*. The proper adjustment or mode of observing the *zero* or 0 division of the column of mercury is by observing it in the transparent part of the box *b*, which has a glass reservoir for the quicksilver, and an edged piece of metal attached to the external part of it; with the edge of which the mercury is to be brought into contact, by turning the screw *f* to the right or left, as occasion requires. The vernier piece at *a*, which determines the altitude of the mercurial column, is first brought down by the hand to a near contact, and then accurately adjusted by turning the screw *h* at the top. The divisions annexed to the tube of this instrument may be of any kind, or of any degree of minuteness, according to the purpose it is intended to serve. To accommodate it to the use of foreigners as well as the English, there are commonly added scales of both French and English inches, with the requisite subdivisions. It is usual to place the French scale of inches on the right side at *ag* from 19 to 31 inches, measured from the zero or surface of the mercury in the box *b*; each inch being divided into lines or 12th parts, and each line subdivided by the vernier into 10th parts: so that the length of the mercurial column may be determined to the 120th part of a French inch. The other scale, which is placed on the left side of the instrument, is divided into 20th parts of inches, and these again into 25th parts, by means of the vernier; thus measuring to 500ths of an English inch: and the divisions on the vernier scale are marked double what they really are, in order that the measures may be expressed in thousandth parts of an inch, for the convenience of calculation.

To this instrument a thermometer is always attached, as a necessary appendage; being fastened to the body at *c*, and sunk into the surface of the frame to preserve it from injury: the degrees of this thermometer are generally marked so as to indicate

the divisions both of Fahrenheit's and of Reaumur's scale. (See THERMOMETER.) Also on the right hand of these two scales is a third, called scale of *correction*, with the words *add* and *subtract* marked; thus serving to show the necessary correction of the observed altitude of the mercury, at any given temperature of the air indicated by the thermometer.

A very considerable improvement in the construction of the portable barometer has been made by Sir H. C. Englefield. In his construction, lightness, firmness, and ease of application, are blended. The barometer tube is about $33\frac{1}{2}$ inches in length; its bore one tenth of an inch in diameter, and the external diameter three tenths of an inch. The cistern is of box, perfectly cylindrical, an inch in its internal diameter, and an inch in depth. A short stem projects from its top (when in the position for observations), to give a firmer hold to the tube. This stem has a perforation sufficiently large to admit the tube, which is glued to it in the usual way. The tube reaches to the middle of the depth of the cylinder, the bottom of which is closed by a screw-cap and leather. This tube being filled and boiled in the common way, and the instrument held inverted in a perpendicular position, mercury is poured into the cistern till it is filled within a fifth of an inch of the top: then the lid is firmly screwed on, and secured from being opened by a small screw passing through its side. The end of the tube in the cistern can never be uncovered by the mercury in any possible position, and of course no air can ever enter it: and since the areas of the cistern and the tube are as the squares of the diameters, it may easily be shown that the mercury must fall $18\frac{1}{5}$ inches before the cistern is quite full, a space more than adequate to the measure of the highest mountains on the earth. When this barometer is set upright the atmosphere acts upon it through the pores of the wood. The variations of altitude in this instrument, when the dimensions are as above stated, will be one ninety-first part less than in a barometer furnished with an apparatus for bringing the surface of the mercury in the cistern to a fixed level: this defect might be remedied by a correspondent division of the scale; but it is much more convenient to divide the scale to real inches, and make the necessary allowance in the result. This barometer is mounted in a mahogany tube of the size of a walking-stick, and has attached and detached thermometers.

For the observation of the height of the mercury, two opposite slits are cut in the mahogany tube, reaching from about 32 to 20 inches, for the longer scales, or from 32 to 25 for such as are intended to be used in this country. The front slit has its sides bevelled, and is exteriorly about $\frac{3}{4}$ of an inch wide;

having a brass plate fixed on one side, divided, as usual, to inches, tenths, and twentieths. On this plate slides a nonius moveable by a small knob, which reads off, as in other barometers, to the 500th of an inch: to this nonius is attached a small portion of brass tube, which embraces the barometer tube; its lower edge being in observation made a tangent to the convex surface of the mercury, as in other well-constructed barometers, and the very narrow slit behind furnishes sufficient light for observation.

When Sir Henry proposes to make an observation, about five minutes before he arrives at the place he takes out the detached thermometer from its place in the end of the mahogany tube, holding it by the upper end at nearly arm's length from his body, and, if the sun shines, in the shade of his person: it very soon takes the temperature of the air, and is not sensibly affected by the heat of the hand. The heat being observed and written down, the barometer is turned up, the brass tube half turned, and the instrument held between the finger and thumb of the left hand above the slide, so as to let it hang freely in a vertical position. Since few persons, if any, have sufficient steadiness of hand to prevent little vibrations in the mercury in this position, the hand should be either rested against any fixed body, or, if no such occurs, by kneeling on one knee; the cistern should be let down so as to touch the ground, the left hand holding the barometer in a vertical position, which a little practice will render easy. The index must then be moved by the knob till its under surface is tangent to the mercury: and a few slight taps should be given to the tube, to ascertain that the mercury is fallen as low as it can. The height being then read off and registered, together with that of the attached thermometer, the brass tube is turned back so as to cover the slits, the instrument gently inverted, and the whole is finished in about two minutes.

Sir Henry does not detail the rules by which the altitude may be deduced from the observations, since these have been given by many authors. But he furnishes a table which indeed is engraven on the barometer, that will enable a traveller to compute altitudes with great facility; the results not deviating far from the truth. He remarks that observations with a single barometer may lead to tolerably accurate results; and states his method of proceeding; which, however, need not here be detailed. The weight of this improved barometer does not exceed a pound and a half. The maker is Mr. Jones, of Charing Cross.

Several minutiæ in the mechanical construction of these instruments will be more obvious from a few minutes' inspection

than by any further details here. The rules for their use in the ascertaining of altitudes may be learnt by turning to the theoretic part of this work; book iv.

BEAM COMPASSES. See COMPASSES.

BEER-DRAWING MACHINES are contrivances by means of which the beer is drawn from three or four casks at once, from cocks standing in one frame, in the bar of a tavern, or any convenient place above a cellar. These machines are nothing else than an assemblage of small pumps, either sucking or forcing, whose pipes of communication are attached to the lower parts of the respective casks from which the liquor is drawn. The motion is given to the piston sometimes by levers, at others by cranks; most frequently, we believe, by means of a hammer-formed lever moving in a vertical plane.

BELLOWS, an instrument constructed for the purpose of alternately drawing and expelling air. In the common culinary bellows the air rushes in at a hole or holes in the bottom, called feeders, over which is a flapping valve, and is expelled through a conical pipe called the nozzle, by means of a kind of mechanism which is too well known to need any description here.

It is not the impulsive force of the blast that is wanted in most cases, but merely the copious supply of air, to produce the rapid combustion of inflammable matter; and the service would, in general, be better performed if this could be done with moderate velocities and an extended surface. What are called air-furnaces, where a considerable surface of inflammable matter is acted on at once by the current which the mere heat of the expended air has produced, are found more operative, in proportion to the air expended, than blast-furnaces animated by bellows. There is, indeed, a great impulsive force required in some cases; as, for blowing off the scoriæ from the surface of silver or copper in refining furnaces, or for keeping a clear passage for the air in great iron furnaces. But in general we cannot procure this abundant supply of air in any other way than by giving it a great velocity by means of a great pressure or impulse; the air is admitted into a very large cavity, and then forcibly expelled from it through a small orifice.

The method of producing a continual blast by a centrifugal force has been long known, being mentioned by *Agricola, de Re Metallica*, lib. 6. p. 62. But the first bellows acting upon this principle, of which we recollect a distinct account amongst the moderns, is that invented by M. Teral, in 1729, and described in the *Recueil des Machines approuvées par l'Academie Roy. des Sciences, tome 5*. This machine is represented in fig. 7. pl. VIII. where AB is a cubical box, with a top rather

arched: to this box is adapted a hollow pyramidal frustum C, at the extremity of which is the tube or nozzle D; the capacity of the pyramid not being separated from that of the box. This box contains an arbor or shaft carrying vanes, as GF, posited horizontally, and which are here placed, as it were, out of the box, that their shape and number may be seen. The ends of the arbor run in a proper collar on each side of the box, and one end, as F, passes through the side of the box, and carries a pulley: over this pulley passes a cord or band, which also runs round part of a wheel HI, situated at some distance from the bellows, and which is turned by the handle M. Thus it will be manifest, that as this handle turns the wheel HI, it will, by means of the band, turn the pulley F and the arbor and vanes, with a velocity which will be to that of the wheel as the radius of the wheel to that of the pulley. Hence the greater the diameter of the wheel, and the less that of the pulley, the more rapidly will the exterior air (which enters by small holes *hh*, into the top of the box) be driven by the vanes, and compressed into the truncated pyramid *c*, and thence expelled at D, in a continued blast; which will likewise be the more violent the greater the action at the handle M. This machine, being very simple, is easily constructed, and at a small expense.

Another bellows, furnishing a uniform blast, is described in the article PNEUMATICS, *Encyclopædia Britannica*, as below: one cylinder is made to deliver its air into another cylinder, which has a piston exactly fitted to its bore, and loaded with a sufficient weight. The blowing cylinder ABCD (fig. 3. pl. VIII.) has its piston P worked by a rod NP, connected by double chains with the arched head of the working beam NO, moving round a gudgeon at R. The other end O of this beam is connected by the rod OP with the crank PQ of a wheel-machine; or it may be connected with the piston of a steam-engine, &c. &c. The blowing cylinder has a valve or valves E in its bottom, opening inwards. There proceeds from it a large pipe CF, which enters the regulating cylinder GHKI, and has a valve at top, to prevent the air from getting back into the blowing cylinder. It is evident that the air forced into this cylinder must raise its piston L, and that it must afterwards descend, while the other piston is rising. It must descend uniformly, and make a perfectly equable blast.

Observe, that if the piston L be at the bottom when the machine begins to work, it will be at the bottom at the end of every stroke, if the *tuyere* T emits as much air as the cylinder ABCD furnishes; nay, it will lie a while at the bottom; for, while it was rising, air was issuing through T. This would make an interrupted blast. To prevent this, the orifice T must be

lessened; but then there will be a surplus of air at the end of each stroke, and the piston L will rise continually, and at last get to the top, and allow air to escape. It is just possible to adjust circumstances, so that neither shall happen. This is done easier by putting a stop in the way of the piston, and putting a valve on the piston, or on the conducting pipe KST, loaded with a weight a little superior to the intended elasticity of the air in the cylinder. Therefore, when the piston is prevented by the stop from rising, the shifting valve, as it is called, is forced open, the superfluous air escapes, and the blast preserves its uniformity.

The Hydraulic Forge Bellows, of Mr. J. C. Hornblower, is a very ingenious contrivance, and is therefore described here. This invention is shown in plate V.

A the plunger, or working part of the bellows, 18 inches square within, which receives the air by a valve in the hinder part opening inwards, which at the stroke by the rockstaff E throws it down the tube indicated by the dotted lines, which has a valve opening into the reservoir D, whence it is led to the tuyere by the pipe P. Length of the plunger 20 inches, stroke nine inches. Diameter of P three inches; of the nozzle 0·6.

The whole is placed in a pit or cistern, having water sufficient to rise to the lower end of the tube where the valve hangs; this tube is the only communication between the upper part and the reservoir D: when as much water is poured in round the working part, over the wash-boards, as will rise within five inches of the upper edge of them, the bellows is ready for use. The little frame-work serves to keep it from rising, and affords a convenient support for the balance and the rockstaff. The area of the pit or cistern ought to be at least twice as much as that of the plunger A.

Mr. Hornblower mentions a very striking difference between the effect of this bellows and a common leathered 30-inch bellows in the same shop. The leathered bellows throws considerably more air to the fire, and its nozzle compared with this is as ·73 to ·60 in diameter, but it does not produce so great an effect in bringing on the heat, and the noise of this is so great as almost to drown that of the common one. The only difference in other respects is, that in the hydraulic bellows the pipe goes under ground for about eight feet, and the conducting pipe of the other comes down about the same distance from the shop above.

When bellows are made more than usually large, for extensive furnaces, they have been frequently worked by water-wheels. But iron furnaces have, of late, been constructed of

such magnitude, that no leather bellows could be made sufficiently capacious; and hence large forcing pumps have often been substituted for them. One of the blowing engines used at the Carron iron works, and constructed by the celebrated Smeaton, is described, with an illustrative plate, in the second volume of the PANTOLOGIA, to which the reader must be referred.

The blowing machine recently erected at the smithery in his Majesty's Dock-yard, Woolwich, if not the most powerful, is perhaps one of the most perfect in the kingdom, and is deserving of particular attention: it is adequate to the supply of air for forty forge fires, amongst which are several for the forging anchors, iron knees, and many other heavy pieces of smithery.

This machine is represented in plate XLI. fig. 1, being a perspective view of the engine, and fig. 2, 3, and 4, elevations and sections of the blowing cylinders. The part seen in fig. 1. is only that which appears above the level of the floor. The other part is below, and may be seen in fig. 2, 3, and 4.

The length of the cylinders is five feet five inches, of which two feet four inches appear above the floor; the interior diameter of each cylinder is four feet eight inches, and the length of the stroke is also four feet eight inches; which is repeated in each of the three cylinders A, B, C, twenty times per minute, which corresponds to an expulsion of nearly 5000 cubic feet of air per minute. The fourth cylinder D is used only to regulate the pressure, as will be explained below.

The manner of communicating motion to the piston rods will be seen in the plate; this motion being so contrived, that while one piston rod is at its highest point, another is half way down, or up, and the other quite down. A large iron wind chest, twenty-two feet five inches in length, is placed on proper stone supports or pillars in the cellar below, and upon this are fixed the four cylinders A, B, C, D, the latter being open to the chest at its bottom, but the others are closed. From this chest, under the cylinder C, proceeds the main eduction pipe, shown in the elevations fig. 3 and 4, and from this branch pipes proceed to the several forges, each pipe near the forge being furnished with a cock, so that the blast may be turned on or off at pleasure.

In fig. 3, above referred to, will be seen a short cylinder behind the eduction pipe, in which is a valve, shown more particularly in fig. 2, where the section is made to pass through the axis both of the valve cylinder and blowing cylinder; the former elevation being at right angles to the principal axis of the

machine, and that in fig. 4, parallel to the same, neither of which therefore embrace the valve cylinder, which is placed somewhat on one side.

On the principal axis, fig. 1, are seen three eccentric wheels, furnished with iron straps, fig. 3, which are connected with the lever under the wind chest, seen at fig. 3, at E; and these wheels are so arranged, in respect to the corresponding crank, that when the piston of any cylinder is either above or below, the lever, fig. 3, is horizontal, and the valve *a* then exactly closes the hole *h*, fig. 2. When the piston in this figure begins to ascend, the end E of the lever, fig. 3, continues to ascend also, and the other end F descends; and being connected with the valve rod at G, fig. 2, this also descends, and thereby opens a communication between the interior of the cylinder and the atmosphere, which former thus receives a fresh supply of air. This valve continues to descend till the piston is half way up; it then begins to ascend till the piston is at its highest point, when the valve has again exactly the position shown in the figure. The piston now descends, but the valve rod still continues to ascend, and thereby opens a communication between the cylinder and wind chest, into which latter the air is forced by the action of the piston. When this latter is half way down, the valve rod has reached its highest point, and then continues to descend with the piston till the latter is down, when the hole *h* is again covered with the valve, and the whole is situated, as at first, to have the process again repeated, as above described. By these means the cylinders are successively opened to the atmosphere, and then to the wind chest, and a constant influx of air is produced. To preserve a steady action in the valve rods, they are made to pass through guards level with the floor, as shown in fig. 1 and 2. The cylinder D has no bottom, being open to the wind chest, and its piston, which weighs 700 lbs. serves only to regulate the pressure, which amounts to about $\frac{1}{2}$ lb. per square inch. When the pressure exceeds this, the piston rises, and opens a safety valve connected with this cylinder at the back, not seen in our drawing, but the operation of which will be easily conceived.

The form of the bottom of the cylinder, shown in fig. 2, is peculiar only to that particular section; the other part of the bottom is perfectly flat: its purpose is obviously to furnish a communication with the valve cylinder. (*Encyclopædia Metropolitana.*)

BELLOWS, *or blowing engine by water.* A machine of this kind, in which the stream of air is supplied by the flowing of water, has been long employed at the iron works of Poullaouen in France. The shower of water, in its descent through the

vertical pipe of the machine, carries down a mass of air along with it (upon the principle of the lateral adhesion of fluids), in the same manner as a shower of rain on the flat surface of the sea produces that temporary blast of wind which the seamen term a squall. Its effects in producing a blast of air are inferior to that of the steam engine; but in situations which afford a plentiful supply and a sufficient fall of water, it may frequently be employed with advantage.

BLOCK MACHINERY. The machinery for manufacturing ships' blocks in the royal dock-yard at Portsmouth, invented by Mr. Brunel, is greatly and deservedly celebrated. A concise account of it is, therefore, here given.

The machines devoted to this purpose have been separated into four classes. 1. The sawing machine, for converting the large timber into proper dimensions for the small machines to operate upon. 2. Those machines which are employed in forming the sheaves. 3. Those which form the iron pins for the blocks. 4. Those by which the shells of the blocks are manufactured. They are all worked by means of two steam engines, each of thirty-horse power. Either of these can be applied indifferently to work the chain pumps, or for turning the wood-mill; and their power is transmitted by a train of wheel-work, to a horizontal shaft, extending along the centre of the middle building, very near its roof. Upon this are a number of wheels and drums, which, by endless ropes and straps, communicate motion to the several subordinate machines.

The order of the processes is this. The elm trees are first cut into short lengths, proper to form the various sizes of blocks, by two large sawing machines, one a *reciprocating*, the other a *circular* saw. These lengths of the trees are next cut into squares, and ripped or split up into proper sizes by four sawing benches with circular saws, and one very large reciprocating saw, which is employed for cutting up the pieces for very large blocks.

The scantlings, thus prepared for the blocks, are perforated in three *boring machines*, with a hole through each to contain the centre pin for the sheaves of the block, and as many other holes in a direction perpendicular to the former, as the number of sheaves it is to have; these holes being intended as the commencement of the several mortises to contain the sheaves.

The blocks are next mortised in three *mortising engines*, which elongate the holes abovementioned to their proper dimensions. Here the motion of the sliding frame for the chisels is communicated to it by means of a long working beam or lever, extending the whole length of the frame at the top of it. At one end it is united by a connecting rod with the chisel frame;

and at the other it is fixed to an axis, which is supported by the framing, and which forms its centre of motion. A connecting rod is joined to it in the middle of the beam; the lower end of which is worked by a crank, formed in the middle of the main axis, which is situated in a direction perpendicular to that which we have described, and is supported in the framing. It is provided with a cone for casting off the movement. The engine with the beam acts with surprising rapidity, making upwards of 400 strokes per minute, at every one of which it cuts out a chip from each mortise as thick as pasteboard. Its movement is, indeed, so rapid, that the chisels cannot be distinctly seen when it is at work; so that the mortises seem to lengthen, and chips to fall out, without any evident cause.

The angles of the blocks are next cut off by three circular saws, as preparatory to reducing them to the elliptical figure.

The outside surfaces of the block are then formed to their true figure by three *shaping engines*, each of which forms every part of ten blocks simultaneously.

The scores, or grooves, round the block are next formed, to receive the rope or strap by which they are suspended: this is effected by two *scoring engines*.

Then the blocks are trimmed by manual labour, to smooth and polish them.

In order to make the sheaves, the first process is cutting pieces or flakes off the end of the trees of lignum vitæ, of a suitable thickness to form the sheaves. This is accomplished by a reciprocating and two circular saws. These flakes are made circular, and the centres pierced in two rounding and centering machines, or trepan saw.

A hole is next excavated in the centre of each sheave, to inlay the coak or piece of bell metal, which is fitted into the centre of each sheave, to form a socket for the centre pin. The centre holes through the coaks are next broached out to a true cylinder in three *broaching machines*.

The last process is turning the faces and edges of the sheaves to a flat surface, in three *facing lathes*, which also form the groove round the edges for them, for the rope which encompasses them when in the block.

There are also two machines for making what are denominated dead eyes, which are very ingenious and complete. The whole number of machines here employed is 47. To describe them minutely would require a volume. A good account of them, illustrated by excellent engravings, may be seen in *Rees's New Cyclopædia*, art. MACHINERY.

BORING *of Cylinders, Ordnance, Wooden Pipes, &c.* See CYLINDERS, ORDNANCE, and PIPES.

BRAMAH'S MACHINE, *Bramah's Hydrostatic Press, &c.* —names which are now commonly given to the ingenious contrivances of the late Mr. Bramah, by which he applied the *quaqua versum* pressure of fluids as a very powerful agent in many kinds of machinery requiring motion and force. These contrivances (for which Mr. Bramah took out a patent in March, 1796) consist in the application of water, or other dense fluids, to various engines, so as, in some instances, to cause them to act with immense force; in others, to communicate the motion and powers of one part of a machine to some other part of the same machine; and, lastly, to communicate the motion and force of one machine to another, where their local situations preclude the application of all other methods of connexion.

The first and most material part of this invention will be clearly understood by an inspection of fig. 4. pl. IX. where "A is a cylinder of iron, or other materials, sufficiently strong, and bored perfectly smooth and cylindrical; into which is fitted the piston B, which must be made perfectly water-tight, by leather or other materials, as used in pump-making. The bottom of the cylinder must also be made sufficiently strong with the other part of the surface, to be capable of resisting the greatest force or strain that may at any time be required. In the bottom of the cylinder is inserted the end of the tube C; the aperture of which communicates with the inside of the cylinder, under the piston B, where it is shut with the small valve D, the same as the suction-pipe of a common pump. The other end of the tube C communicates with the small forcing-pump or injector E, by means of which water or other dense fluids can be forced or injected into the cylinder A, under the piston B. Now, suppose the diameter of the cylinder A to be 12 inches, and the diameter of the piston of the small pump or injector E only one quarter of an inch, the proportion between the two surfaces or ends of the said pistons will be as 1 to 2304; and supposing the intermediate space between them to be filled with water or other dense fluid capable of sufficient resistance, the force of one piston will act on the other just in the above proportion, viz. as 1 is to 2304. Suppose the small piston in the injector to be forced down when in the act of pumping or injecting water into the cylinder A, with the power of 20 cwt. which could easily be done by the lever H; the piston B would then be moved up with a force equal to 20 cwt. multiplied by 2304. Thus is constructed a hydro-mechanical engine, whereby a weight amounting to 2304 tons can be raised by a simple lever, through equal space, in much less time than could be done by any apparatus constructed on the known

principles of mechanics; and it may be proper to observe, that the effect of all other mechanical combinations is counteracted by an accumulated complication of parts, which renders them incapable of being usefully extended beyond a certain degree; but in machines acted upon or constructed on this principle every difficulty of this kind is obviated, and their power subject to no finite restraint. To prove this it will be only necessary to remark, that the force of any machine acting upon this principle can be increased *ad infinitum*, either by extending the proportion between the diameter of the injector and the cylinder A, or by applying greater power to the lever H.

"Fig. 5. represents the section of an engine, by which very wonderful effects may be produced instantaneously by means of compressed air. AA is a cylinder, with the piston B fitting air-tight, in the same manner as described in fig. 4. C is a globular vessel made of copper, iron, or other strong materials, capable of resisting immense force, similar to those of air-guns. D is a strong tube of small bore, in which is the stop-cock E. One of the ends of this tube communicates with the cylinder under the piston B, and the other with the globe C. Now, suppose the cylinder A to be the same diameter as that in fig. 4. and the tube D equal to one quarter of an inch diameter, which is the same as the injector, fig. 4.: then, suppose that air is injected into the globe C (by the common method), till it presses against the cock E with a force equal to 20 cwt. which can easily be done; the consequence will be, that when the cock E is opened the piston B will be moved in the cylinder AA with a power or force equal to 2304 tons; and it is obvious, as in the case fig. 4. that any other unlimited degree of force may be acquired by machines or engines thus constructed.

"Fig. 6. is a section, merely to show how the power and motion of one machine may, by means of fluids, be transferred or communicated to another, let their distance and local situation be what they may. A and B are two small tubes, smooth and cylindrical; in the inside of each of which is a piston, made water and air tight, as in figs. 4. and 5. CC is a tube conveyed under ground, or otherwise, from the bottom of one cylinder to the other, to form a communication between them, notwithstanding their distance be ever so great; this tube being filled with water or other fluid, until it touch the bottom of the piston; then, by depressing the piston A, the piston B will be raised. The same effect will be produced *vice versa:* thus bells may be rung, wheels turned, or other machinery put invisibly in motion, by a power being applied to either.

"Fig. 7. is a section, showing another instance of communicating the action and force of one machine to another; and how

water may be raised out of wells of any depth, and at any distance from the place where the operating power is applied. A is a cylinder of any required dimensions, in which is the working piston B, as in the foregoing examples: into the bottom of this cylinder is inserted the tube C, which may be of less bore than the cylinder A. This tube is continued, in any required direction, down to the pump cylinder D, supposed to be fixed in the deep well EE, and forms a junction therewith above the piston F; which piston has a rod G, working through the stuffing-box, as is usual in a common pump. To this rod G is connected, over a pulley or otherwise, a weight H, sufficient to overbalance the weight of the water in the tube C, and to raise the piston F when the piston B is lifted: thus, suppose the piston B is drawn up by its rod, there will be a vacuum made in the pump cylinder D, below the piston F; this vacuum will be filled with water through the suction pipe, by the pressure of the atmosphere, as in all pumps fixed in air. The return of the piston B, by being pressed downwards in the cylinder A, will make a stroke of the piston in the pump cylinder D, which may be repeated in the usual way by the motion of the piston B, and the action of the water in the tube C. The rod G of the piston F, and the weight H, are not necessary in wells of a depth where the atmosphere will overbalance the water in the suction of the pump cylinder D, and that in the tube C. The small tube and cock in the cistern I are for the purpose of charging the tube C."

By these means it is obvious most commodious machines of prodigious power, for tearing up trees, drawing piles, &c. and susceptible of the greatest strength, may readily be formed. If the same multiplication of power be attempted by toothed wheels, pinions, and racks, it is scarcely possible to give strength enough to the teeth of the racks, and the machine becomes very cumbersome and of great expense. But Mr. Bramah's machine may be made abundantly strong in very small compass. It only requires very accurate execution. Mr. Bramah, however, was greatly mistaken when he published it as the discovery of a *new* mechanic power. The principle on which it depends has been *well known* for nearly two centuries; and it is matter of surprise that it has never before been applied to any useful practical purpose.

BRIDGES *of Suspension*, or those in which the passage across a river is effected by suspending the supporting material above the water, are now becoming so common in this country, that an article on the subject seems highly desirable.

The common method of crossing ravines and rivers in the interior of America and India is by means of ropes of various kinds, which are stretched from side to side, having sometimes

a road-way upon them, forming a complete rope-bridge; and in other cases merely a basket suspended from them, which is drawn across whenever it is necessary to convey a traveller over.

Iron chains, rods, and wires, have, however, been most successfully employed for the same purpose; and they have been applied in various ways. The following brief history, with an account of a suspension bridge across the Kelvin, is taken from that useful little publication *The Glasgow Mechanic's Magazine.*

Chain bridges of very great extent are said to have been long in use in China, and Major Rennel describes one of 600 feet in length, which is thrown across the Sampoo of Hindostan. The first chain bridge erected in this island was Winch Bridge, which was thrown across the river Tees, in 1741, over a chasm nearly 60 feet deep, for the passage of travellers, but particularly of miners; it is seventy feet in length, and about two feet broad, with a hand rail on one side, and planked in such a manner, that the traveller experiences all the tremulous motion of the chain, and sees himself suspended over a roaring gulf, on an agitated and restless gangway, to which few strangers dare trust themselves.

Bridges on this plan were subsequently erected in the United States of America; and there is one (erected in 1809,) over the river Merrimack, in Massachusets, of 244 feet span, having two carriage ways, each fifteen feet in breadth, and capable of supporting 500 tons. There is also another fine suspension bridge of five arches over the Delaware at Trenton; of which an interesting account has been published in this country by Mr. C. A. Busby. The following suspension bridges have been recently erected in Scotland:

	Date.	*Span.*	*Breadth.*	*Cost.*
Galashiels Wire bridge	1816	111 feet	———	£40
King's Meadows do.	1817	110 do.	4 feet	£160
Thirlestane do.	———	125 do.	———	———
Dryburgh Chain do.	1818	260 do.	4 do.	£720
Berwick Union do.	1820	361 do.	18 do.	£6050

The suspension bridge across the Menai-straits furnishes also a very interesting specimen of this department of the art.

The suspension bridge across the river Kelvin, exhibited in plate XLII, was erected in the year 1822, by James Gibson, of Hillhead, Esq., for the purpose of connecting the lands of Hillhead and Blythswood. It was designed and executed under the superintendence of John Herbertson, jun., Architect, on the principle of suspension bridges, with the chains or rods

below, and the weights resting on the rods by means of cast-iron brackets, on which the beams are placed.

The bridge is 63 feet in span, and twelve feet wide, and there are five beams of crown memel in the width, each being twelve inches deep, by six inches thick, in two lengths. The rods which are made of Ackerman's chain iron are one and one-fourth inches in diameter. They are bent round the ends of the beam, and fastened with a hoop of iron, two inches broad, by one inch thick, to prevent it from springing. Buckling screws are placed on each rod, near to the brackets, for the purpose of tightening the rods and raising the beams to the level; so that the whole structure can be adjusted with the greatest ease.

That this plan may be carried to a great extent, is evident from its simplicity and capability of sustaining an enormous pressure. From the construction, it will be easily seen, that the whole weight or pressure is exerted on the iron rods, or wires, in the direction of their length, so that they have no tendency to break or bend in a lateral direction. The amazing strength that this mode of connecting the ends of a wooden beam imparts to it, may be illustrated by a very simple experiment. Let the mechanic take a piece of wood, about two or three feet long, and an inch in diameter, place the ends of it between two chairs, or stones, and attempt to stand upon it, and he will find it break almost instantaneously. Let him now take a similar piece of wood, and bend round the two ends a piece of wire so much longer than the wood as to allow a small wedge, or wooden pin, two or three inches long, to be placed vertically between the wood and the wire, and he will find that he will be unable to break it, though he leap upon it with all his force. The application of this principle may be seen in all cases where brackets and trussed beams are employed, though it has been seldom perhaps carried to the extent which it obviously admits of.

But for a fuller development of the principles and construction of suspension bridges, we here present copious extracts from *Mr. George Buchanan's* report on the practicability of erecting a suspended bridge of iron, across the Esk at Montrose, instead of the present wooden bridge there. (*Edinburgh Phil. Jour.* No. 21.)

The town stands on a gently rising ground, in one of those low sandy flats, which occur so frequently on the shores of the German Ocean, and which, from their slight elevation above the sea-level, and other circumstances, appear to have been once overflowed by the water. It has the German Ocean on the east, at the distance of about half a mile, and to the west is a tract of

low and level sands, above four square miles in extent, and nine miles in circumference, through which the South Esk winds its way to the sea, passing close to the town on its south side. These sands lie below the level of high water and above the level of low water, and the river opening a communication with the sea, it necessarily happens, that every rising tide rushes up the channel of the river, and inundates the whole of this sandy flat to the west of the town, which is again left uncovered by the reflux of the tide. The channel through which this great body of water is alternately poured in and discharged is suddenly contracted at the south end of the town, to the breadth of 700 feet at high water, and 400 feet at low spring-tides; and in consequence of this, the stream rushes in or out with great violence, according as the tide is either flowing or ebbing; and it is over this narrow part of the channel that the bridge is erected; the narrowness here, which both strengthens and deepens the current, rendering the situation in other respects favourable for a structure of this nature.

This low land, over which, at each return of the tide, are spread the waters of the ocean, after they have made their way through the narrow channel of the South Esk, is called the Basin, which forms a striking object in the scenery of the place, appearing, when the tide is full, a large and beautiful lake, and in a few hours afterwards, when the waters have retired, a desolate and sandy marsh. But what we have chiefly to consider here, is the difficulty in finding in such a situation any solid foundation for the erection of a bridge. In consequence of the violence with which the water flows out and in, as the basin is alternately emptied and filled, the natural channel of the river has been deepened, and now contains in the middle parts a body of 30 or 35 feet of water at full tide, and never less than 20 feet at the lowest tides. The current also often runs at the rate of five or six miles an hour. The river Thames at London is broader than this stream, but its depth is much less, and its current is not nearly so rapid. Estimating the average depth of the basin to be six feet at high water, and its area four square miles, we shall find that the body of water discharged through this channel is equal to that of a river which drains a country 10,000 square miles in superficial extent, a surface far exceeding that which is drained by the principal rivers of our island, and more than double the area drained by the Thames itself. It is not therefore merely a fresh-water stream over which we have to build, nor yet, strictly speaking, an arm of the sea. It is a vast river from the ocean, pouring in with rapid stream on our works, and in a channel already of uncommon depth, and at the same time so confined, and of so soft and yielding a bot-

tom, that the least contraction of the water-way is sure to deepen it still farther, and thus endanger any work erected on so precarious a foundation, should the attempt even succeed of founding and building, in a situation so replete with difficulty and hazard.

At the place where the present bridge stands, the river is divided by a small island called the Inch into two streams, which again unite at a quarter of a mile below the bridge. It is over the northern and larger stream that the bridge is erected; and it is evidently a very appropriate situation for a suspension bridge.

The suspended arch is, in most respects, the reverse of the common arch. The common arch, it is well known, is only sustained in consequence of the nice balance and adjustment of its several parts. But the materials of the arch and its roadway lying above the abutments from which the arch is sprung, the whole rests or stands on these supports, and on this account the equilibrium of the arch is of an unstable and precarious nature, so that whenever it is disturbed beyond a certain point, it is sure to be completely overturned. When the bridge, therefore, is overloaded in any part, the fall of the whole structure is inevitable. The suspended arch is the reverse of this, and has, in this respect, the advantage. There is here also an equilibrium between the different parts of the structure, but as the materials of the arch and its roadway lie, in this case, below the suspending pillars, the whole rather hangs than rests on these pillars, and the equilibrium is, on this account, remarkable for its stability. It is that kind known under the name of the Stable Equilibrium; while the other, being less sure, is entitled the Tottering Equilibrium. The one cannot be overset, but the other requires considerable skill to be maintained. While the raised arch, therefore, falls irretrievably in consequence of any overload, the hanging arch cannot give way until the materials themselves which compose it are torn in pieces. The one tumbles long before the arch stones are strained to their utmost; while the other carries the load on its chains to the very moment of their fracture. In the one case the materials may be driven out of their place, and thus the structure may be overturned; while in the other, we have the whole strength of the materials as a security against accidents. And although the common bridge is, no doubt, seldom known to fail, its strength and solidity are chiefly owing to the enormous mass of materials which compose it; while the suspended bridge, on the other hand, is distinguished by the lightness of its structure, and the apparent boldness of its design.

But malleable iron possesses a peculiar advantage in its tena-

city; it stretches long before it actually breaks; it begins to stretch, indeed, with about one-third, or, at most, one-half of the weight which would tear it asunder; and, as it is unsafe to load it with any more than this third or half of its utmost strength, at least if we wish to give permanence to the structure, this circumstance ensures the highest degree of security that can be desired: for even if the strength of the iron should happen to be estimated too low, which, however, cannot take place, if we are careful to prove each link of the chains before they are put together; but should this improbability even occur, and should the load, for example, of an assembled multitude begin to stretch the chains, this circumstance could not fail to be observed. The sinking of the roadway would signify the approach of danger long before any accident could happen: so that if the structure be combined with proper attention and skill, the actual breaking of the chains is a contingency which cannot take place by any possible concurrence of accidents.

In such bridges, then, it appears the utmost security is obtained in the arch itself, by proving carefully the strength of every bar or bolt of iron, of which the main chains are composed, and also of every joint or fastening, by which these detached bars or pieces are united into one great suspending chain, reaching from end to end of the bridge, there passing over its supporting pillars, and terminating in the ground, on each side. By thus knowing exactly how much each chain will bear, we obtain a safe rule for applying such a number as will cover every emergency.

In regard to the towers for supporting the bridge on each side, such strong and substantial pillars of stone and iron can be erected for this purpose, as to render it impossible that they should be crushed under the load they have to sustain. These can be founded also on so broad and ample a basis of pile-work as to prevent them from sinking: and, lastly, they may be secured at the bottom by such sufficient fastenings, that they cannot be overset by any external force or violence to which they are ever likely to be exposed.

To secure the extremities of the chains, these can be carried so deeply under ground, and there bound securely to a platform of pile-work, so firmly and deeply rooted into the soil, and so heavily loaded with stones or gravel, that the chains themselves would be torn in pieces before the load which stretches them could either disengage the fastenings, or pull up the piles. In all these cases, it is only necessary to know exactly the load which is ever likely to be laid on the bridge, or the nature of any external violence which may be apprehended, and to guard these vulnerable points of the structure, by a degree of strength

in the several constructions, proportioned to the strain which each has to bear.

Next, however, to the perfect security of every part of the bridge, we must look to the accommodations; and in this respect the suspended bridge is every way on a par with the common bridge, excepting that the flexibility of the arch subjects it to a certain unsteadiness, which, in some of these structures, has been felt as an inconvenience. This, however, has chiefly arisen from want of the proper means having been taken to prevent it.

In the erection of a suspended bridge, the first object is to ascertain the utmost strain to which the chains will ever be subjected. The strain arises from the weight of the roadway, and of any load of carriages or people that may be laid upon it, together with the weight of the rods by which it is suspended from the main chains, and also the weight of those chains themselves; each and all of these together being sustained by the cohesive strength of the iron, of which those principal chains are composed, and which is stretched in every part of it, exactly as if the chain were hung perpendicularly, and a weight, corresponding to the strain on the bridge, suspended at its lower extremity. It is of the first importance, therefore, to know the total amount of all these different weights, that we may be able to apply a chain, whose collective strength may be amply sufficient to sustain it permanently, without stretching or altering, by the strain, the natural texture of the metal. In the bridge now designed, the roadway is to be 30 feet wide, 28 feet clear of the chains and side-rails, and 20 feet clear of the two footpaths, each of which, therefore, is four feet wide. For the support of the roadway, there are to be only two sets of main chains, one at each side of the bridge, and running in a line above the outside of the footpath, and above the side-rails; so that between the opposite railings of the bridge all is clear foot and carriage way, the footpaths being only raised above the carriage way, and protected from the encroachment of carriages, by short iron posts planted at convenient distances, and connected together, if necessary, by a chain, over which one may easily step.

Mr. B. proposes making the roadway wholly of iron, consisting of a series of iron plates, supported on a frame-work below, and covered above with a coat of gravel or small metal, four inches thick, or more. The weight of the iron-work in the plates, frames, side-rails, suspending and cross rods, and, in short, all the iron-work supported by the chains together, he estimates at 180 tons, and the weight of four inches thickness of gravel at 220 tons.

The greatest load that can ever be laid on the bridge is when it is crowded with people, and Mr. B. estimates the ut-

most number that it will hold at 7000, which is more than half the whole inhabitants of the town. Suppose each person 150lb., or 12 stones and upwards, the total will be nearly 470 tons weight. The weight of the chains themselves will be 100 tons, so that, on the whole, in the most extreme case that can occur, we shall have loading and straining every inch of the chains,—viz.

Iron in roadway and in suspending rods,	180 tons.
Gravel, - - - - - -	220
People, - - - - - -	470
Chains, - - - - - -	100
Total,	970 tons.

We shall be enabled to lay this great load upon the chains with perfect safety, from the circumstance, that, owing to the deepness of the curve, this load will produce no undue strain upon the arch; it will just stretch the chains as if they had been hung perpendicularly, and the weight suspended by their extremities. In the middle of the arch, indeed, the strain on the chains will scarcely be so much as this. This advantage is owing entirely to the height of the towers; for had these been so low as those of the Tweed bridge, compared with its span, the weight of the roadway would have produced on the chains, owing to the flatness of the arch, a strain almost double that of their natural weight, and the carriages and people would all of them have produced an augmented strain in proportion; so that, instead of 1000 tons, we should have had a strain of nearly 2000 tons on every inch in the length of the chains from pillar to pillar, and from thence to the ground *.

* This circumstance of the strain on the chains varying with the depth or flatness of the arch, even though the natural weight hanging upon them be in either case the same, arises, it is well known, from the principle of oblique action.

When a rope or chain hangs perpendicular, and carries a weight at its extremity, it is evidently stretched by a force exactly equal to the weight itself, because the cohesive strength of the rope being always exerted lengthways, this, when the rope hangs perpendicular, is directly opposed to the gravitating action of the weight, and these opposite forces producing an equilibrium, must necessarily be equal. But when the rope is made fast at its extremities to two opposite points of suspension, and the weight suspended between them, the case is quite different: Here the rope cannot hang vertically, as before, but branches off from the point where the weight is attached towards each point of suspension. It thus divides itself into two distinct portions, each of which now bears its share of the load:—and the weight being thus sustained by two ropes instead of one, this, it may be imagined, should reduce the strain upon each one-half, and so it undoubtedly would, if each rope were to hang perpendicular. If the points of suspension were brought together, and the rope thus merely doubled, then it is evident that each half, as it would only bear, so it would only be strained with, the half of the weight. But when the points of suspension are removed from each other, and the rope spans the intermediate distance, then the case is quite different; since the rope instead of hanging vertically, must incline from the points of suspension towards the point where the weight is attached. But as the weight continues to draw directly down-

Good English iron will bear for any length of time, without stretching or altering its texture in any respect, at least 8 tons

wards, and the rope to exert its strength directly lengthways, the forces are hence no more directly opposed to each other. Each branch of the rope bears obliquely upon its object, and before these indirect actions can become a match for the weight, which continues invariably to draw in the line of the perpendicular, they must necessarily acquire additional force, in proportion to their obliquity. If the rope, then, has just strength enough to bear the weight, when the points of suspension are brought together, it will be sure to give way the moment they are separated; and if it has sufficient strength to carry the weight, notwithstanding this separation, each branch will yet be strained by a force, depending not merely on the weight itself, but also on the obliquity of the rope; the more oblique this is to the direction of gravity, the more will it be strained, according to the well known laws of oblique forces.

Such, then, is the reason of that remarkable strain which we observe in flat arches, whether suspended or raised, and of that moderate tension or compression which we obtain by increasing the depth or height of the curve. In the former, the arch hangs or stands every where extremely oblique to the direction of gravity; and the strain therefore, on every part of it, must greatly exceed the natural weight which it supports. In deeper or higher curves, again, the arch hangs or stands less oblique to the perpendicular: the forces of cohesion or of compression, and the force of gravity, are hence more directly opposed to each other, and are therefore more nearly equal. In these cases, the weight is no doubt disposed over the whole length of the arch, instead of being accumulated in the centre; but the effect of this is merely to alter the figure of the curve of equilibrium, in every part of which, however, the strain still invariably depends on the two circumstances already mentioned, namely, the weight which that part sustains, and its obliquity.

Whatever be the disposition of the load, the strain on the arch of a suspended bridge may be easily determined by two simple, but important considerations: 1st, In the middle or lowest part of the curve, the strain in different arches increases exactly as their depth is diminished, and diminishes exactly as their depth is increased, supposing the span to remain the same. In other words, this strain is inversely proportional to the depth, or versed sine of the curve: Secondly, When the depth is the eighth part of the span of the arch, then the strain in the centre is exactly equal to the whole weight of the bridge. In every arch, then, if the depth exceed the eighth part of the span, the strain in the centre will be proportionally less than the natural weight of the bridge; and if the depth be less than the eighth part of the span, this strain will be in the same proportion greater than the natural weight. So that, in general, if the depth be the nth part of the span, then in every case the strain in the centre will be equal to the whole weight of the chains and roadway, augmented or diminished in the ratio of 8 to n. Suppose, for example, the depth to be the 16th part of the span, then $n=16$, and the ratio of 8 to n or 8 to 16, is the same as that of 1 to 2. In the centre, then, the arch will be strained with a force equal to double the natural weight of the bridge. Suppose, again, the depth equal to one-fourth of the span, then $n=4$ and the ratio of 8 to n or 8 to 4, is the same as that of 2 to 1, or one to $\frac{1}{2}$, so that here the horizontal tension is only the half of the weight of the bridge. Let W denote the weight of the bridge and its load, and T the strain in the lowest part, or the horizontal tension, then $T=\frac{nW}{8}$.

The horizontal tension, or the strain in the centre, is less than the strain on any other point, as this increases gradually towards the points of suspension, where it is greatest of all. To find the strain there, however, we have only to add to the horizontal tension the nth part of the weight of the bridge; so that, if t denote the strain at the point of suspension, $t=\frac{nW}{8}+\frac{W}{n}$.

The arch of the chains is usually considered as a catenary curve, and even in this view the above propositions are sufficiently near the truth for practical purposes; for when the depth is the eighth of the span, the strain in the centre, calculated in this manner, is only about $\frac{1}{50}$th part too little. But they will be found much more exact,

of strain upon every square inch. Experiments differ in some degree as to this particular, some carrying the strength much higher; but Mr. Buchanan takes the lowest estimate. We may safely assume the strength at 8 tons to the inch, which is the lowest estimate, and which is only one third of what the iron really will bear without breaking, as it takes from 20 to 30 tons to tear it asunder. Suppose, then, that the bridge is strained with the utmost load of carriages and people that can ever be laid on it, Mr. B. proposes having such a thickness of iron from pillar to pillar to support this load, that no part of it will ever be stretched with a force of more than 8 tons

if we consider that, in suspended bridges, the curve is in general much nearer to a parabola than to a catenary, as the level roadway tends always to bring it nearer to this latter figure, in proportion as its weight exceeds that of the chains. The arch, in fact, is only a catenary, if we suppose the weight of the roadway to be as nothing, compared with that of the chains; and it is an exact parabola again, when the weight of the chains is as nothing compared with that of the roadway; and the latter is in general by much the nearest to the true state of the case. In the bridge above proposed, the weight of the roadway itself is four times that of the chains, and, when loaded to its utmost, it is ten times greater. This consideration is of importance in practice, much embarrassment having been felt in loading the bridge with its roadway, by the weight gradually altering the figure of the curve: and this will always take place if the lengths of the suspending rods be drawn to the curve of the catenary. As the progress of loading proceeds, the figure of the arch will change, the roadway will be drawn off its level, the suspending rods off the perpendicular, and the whole structure will be distorted, besides that different parts of it will be strained beyond what they are intended to bear. To avoid such evils, the length of the suspending rods must be calculated by that figure to which the weight of the roadway will finally bring the chains; and, for this purpose, the curve of permanent equilibrium cannot be too nicely investigated. But for calculating the least and greatest strains in the arch, we may, without sensible error, assume it as a parabola. Now, in all these funicular curves, whether catenary, parabola, or any other figure, it is a general property that the horizontal tension is proportional to the radius of curvature at the vertex; and is, in every case, equal to the weight of as much of the curve as is equal to the radius of curvature in length, and of the same thickness or cross section as the curve at the vertex. But the radius of curvature of the parabola at the vertex is just half the parameter: and hence from the equation of this curve $y^2=px$, we deduce T, the horizontal tension $T=\frac{1}{2}p=\frac{y^2}{2x}$. But y is half the span of the arch $=\frac{1}{2}S$, S denoting the span, and x is its depth or versed sine $=d$; hence $T=\frac{S^2}{8d}$. Let d now be $=\frac{S}{n}$, and $S=nd$, then $T=\frac{nd\times nd}{8d}=\frac{nS}{8}$. But S denotes the weight of a part of the bridge, equal to the span in length, and having every where the same cross section as the chains and roadway in the middle; and this is evidently within a mere trifle of the whole weight of the bridge, only falling short of it by the weight of a part of the chains, equal in length to the difference between the arch and the span, and which will not, in general, amount to the 200th or 400th part of the whole weight. For S, therefore, we may safely substitute W, and this gives the formula $\frac{nW}{8}$, already stated.

For further information on the subject of the catenary, see Professor Leslie's Geometry of Curve Lines, and Elements of Natural Philosophy, where the strain in the lowest part of the catenary is expressed by a very simple, yet tolerably accurate formula, viz. $\frac{b^2}{8d}+\frac{d}{6}$, b denoting the span, and d the depression.—See also Dr. Gregory's Common-Place Book, pa. 177, &c. and pp. 164—167, vol. I. of this work.

to the inch; and thus it will endure, not only for the moment during which this extraordinary strain is ever likely to take place, but although it were continued for any length of time; so that any notion of danger from the utmost load to which it can ever be subjected seems totally out of the question; and much less can any hazard be incurred from the every day traffic on the bridge. The thickness of iron required for this purpose will be about 124 inches, or about 62 on each side of the bridge. There will in fact be less strain by 100 tons in the centre of the arch than at each point of suspension, and the section of iron will require to be varied on this account; but 124 inches is the average; and could we stretch, therefore, one whole arched bar of iron, of this thickness, from pillar to pillar, and from thence to the ground, this would form the most perfect suspending arch. But this is impossible; such a vast mass can only be formed by uniting small pieces together; and it is of importance to consider what is the most convenient size for these pieces. In the Tweed bridge, the chains are formed by round bars or bolts, 15 feet long each, and 2 inches in diameter, each weighing about 2 cwt. The advantage of these large and heavy bars is, that they save joinings; but they are attended with other inconveniences, which more than counterbalance it. Mr. B. prefers bolts of smaller diameter, not exceeding 1½ inch; these can be more easily procured, are easier wrought, and easier put together; so that, on the whole, they are attended with less expense. Another advantage arises from the smallness of these bars; their great number enables us to blend together, in every part of the compound chain, the various qualities of the iron; so that if some bars should be below their proper strength, others will be as much above it, and the collective strength of the whole will still be in every part of the arch rather above than below the standard. A greater number of joints will no doubt be required for the small bars; but this is a matter of little importance, more especially as these can be made of so simple a construction that the bars can be put together and taken to pieces again with the greatest facility.

The following is an abridged account and estimate of the dimensions and structure of the proposed bridge.

Span of the arch, or length between suspending pillars, 420 feet.

Versed sine, or depth of the arch, equal to the height of the pillars above roadway, 60 feet.

Main Chains.—One compound chain on each side of the bridge, consisting of 36 single chains, running parallel to each other, and ranged in a compact square, 6 broad and 6 deep.

Each single chain is $1\frac{1}{2}$ inch diameter; each compound chain has thus a thickness or cross section of $63\frac{1}{2}$ square inches, and both together 127 inches. The single chains are formed of bolts 15 feet long, upset and shouldered at each end, and coupled together with cast-iron coupling blocks 4 inches diameter; the strength of each bolt and coupling being carefully proved to eight or ten tons on the square inch.

Roadway.—30 feet wide; 23 feet clear of chains and side rails; and 20 feet clear of footpaths, each of which is 4 feet wide. Roadway laid with *gravel* or metal 4 or 6 inches deep; this laid on cast-iron plates $\frac{1}{2}$ inch thick; these supported on *malleable iron* joisting frames, crossing under the bridge at every 5 feet in its length, each $3\frac{1}{2}$ feet deep in the middle, and well trussed in every part: these frames united and strengthened by malleable iron plates, 2 feet deep, running longitudinally the whole length of the bridge standing upright, and by their depth giving stiffness to the roadway.—See Pl. XLII.

Suspending Rods.—These are formed of $\frac{3}{4}$th inch bolts, and are placed two together on each side of the bridge, and, at every 5 feet in its length, attached to a socket in the suspending frames below, and to a coupling above, which is attached to the chains, and binds them all into one mass. Similar rods run horizontally from the chains to the pillars, and thence to the descending chains: these serve to keep the arch of the chains steadily in its place, and, interweaving with the upright rods, they communicate a remarkable strength and steadiness to the whole structure.

Pillars.—These are four in number, two at each end of the bridge; each consists of a pyramid, 4 feet square at top, 9 feet at bottom, and 50 feet high, resting on a pedestal 11 feet square and 11 feet high, and the bottom of which is level with the roadway of the bridge. This pedestal rests on a pier of stone, 12 feet square at top, and twenty feet square at bottom, built on the site of the present pier: the bottom is on a level with low water-mark, and founded on a strong basis of planking and piles. The pyramid is composed of iron plates $\frac{1}{2}$ inch thick, cast with flanches, and bolted and rusted together into one mass, the hollow within being built up with stone. The pedestal is either formed in the same manner, or wholly of stone. The base or pier below is built of ashler, and put together in the strongest manner. The pyramid is bolted to an iron plate or frame resting on the top of the pedestal, this to a similar plate below the bottom of the pedestal, and this again to the platform on the top of the piles,—so that one connected chain of iron runs from top to bottom of this compound pillar, and binds the whole into one mass.

Fastenings.—The chains are made fast to their extremities, each to a cast iron bracket, which is bolted to the top of a wooden platform, 20 feet square, and resting and firmly attached to a series of piles, driven deep and firmly into the soil below. The 36 bolts of the main chain, as they approach this platform, are spread out from their compact square of 2 feet to cover the above platform of 20 feet square, and each is then attached to its bracket. The platform is then loaded with sand, or gravel, till the incumbent weight amounts to at least 500 or 1000 tons on each end of the bridge; this being the greatest weight the bridge itself will have to sustain.

Strength.—The bridge will carry, with perfect safety, 7000 people in addition to its own weight; and, with this great load, no part of the chains will be stretched with a greater strain than 8 tons on a square inch, which it is well known common iron will bear with the utmost safety, but which, every bar will be proved to before it goes into the bridge.

Expense.—Estimated at £12,648.

CAMEL is the name given to a machine employed by the Dutch for carrying vessels heavily laden over the sand-banks in the Zuyder-Zee. In that sea, opposite to the mouth of the river Y, about six miles from the city of Amsterdam, there are two sand-banks, between which is a passage called the Pampus, sufficiently deep for small vessels, but not for those which are large and heavily laden. On this account, ships which are outward bound take in before the city only a small part of their cargo, receiving the rest when they have got through the Pampus; and those that are homeward bound must, in a great measure, unload before they enter it. For this reason the goods are put into lighters, and in these transported to the warehouses of the merchants in the city; and the large vessels are then made fast to boats, by means of ropes, and in that manner towed through the passage to their stations.

Though measures were adopted so early as the middle of the sixteenth century, by forbidding ballast to be thrown into the Pampus, to prevent the further accumulation of sand in this passage, that inconvenience increased so much from other causes as to occasion still greater obstruction to trade; and it at length became impossible for ships of war, and others heavily laden, to get through it. About the year 1672 no other remedy was known than that of making fast to the bottoms of ships large chests filled with water, which was afterwards pumped out; so that the ships were buoyed up, and rendered sufficiently light to pass the shallow. By this method, which was attended with the utmost difficulty, the Dutch carried out their numerous fleet to sea in the above mentioned year. This plan, however,

gave rise soon after to the invention of the camel, by which the labour was rendered easier.

The camel consists of two half ships, constructed in such a manner as they can be applied below water, on each side of the hull of a large vessel. On the deck of each part of the camel are a great many horizontal windlasses, from which ropes proceed through apertures in the one half, and, being carried under the keel of the vessel, enter similar apertures in the other, from which they are conveyed to the windlasses on its deck. When they are to be used, as much water as may be necessary is suffered to run into them; all the ropes are cast loose, the vessel is conducted between them, and large beams are placed horizontally through the port-holes of the vessel, with their ends resting on the camel on each side. When the ropes are made fast, so that the ship is secured between the two parts of the camel, the water is pumped from them; by which means they rise, and raise the ship along with them. Each half of the camel is often about 127 feet in length; the breadth at one end is 22, and at the other 13. The hold is divided into several compartments, that the machine may be kept in equilibrio while the water is flowing into it. An East India ship that draws 15 feet of water can, by the help of the camel, be made to draw only 11; and the heaviest ships of war, of 90 or 100 guns, can be so lightened as to pass, without obstruction, all the sand-banks of the Zuyder-Zee.

Leupold, in chap. 6. of his *Theatrum Machinarum*, published in 1725, at Leipsick, describes this machine under the head *Beschreibung der se genannten Camele zu Amsterdam, womit die befrachten Schiffe über dem Pampus gebracht werden*, and says it was invented by Cornelius Meyer, a Dutch engineer. But the Dutch writers almost unanimously ascribe this invention to a citizen of Amsterdam, called Meuves Meindertszoon Bakker.

As ships built in the Neiva cannot be conveyed into harbour, on account of the sand-banks formed by the current of that river, camels are employed also by the Russians, to carry ships over these shoals: and they have them of various sizes. Bernoulli saw one, each half of which was 217 feet long, and 36 broad. Camels are used likewise at Venice. An engraving of the camel may be seen in *L'Art de batir les Vaisseaux*, Amsterdam, 1719, 4to. vol. ii. p. 93.

CANALS, *motion of water in.* See STREAM.

CAPSTAN, a large massy column, shaped like a truncated cone, placed perpendicularly on the deck of a ship, and turned by levers or bars, which pass through holes pierced in its upper extremity; serving, by means of a cable which winds round the

barrel, to draw up burdens fastened to the end of the cable. The power of this machine in its simple state is manifestly reducible to that of the axis in peritrochio. There is frequently attached to it a tackle of pulleys, but the ingenious contrivance described in art. 4. of the introductory part of this volume is far preferable.

CELLAR CRANE, a machine represented in fig. 6. pl. VI.; and is very useful to wine merchants, brewers, &c. in drawing up and letting down casks full of wine, beer, &c. It saves the trouble and inconvenience of horses, and in many places can be used where horses could not. AA are two wooden props, about 6 feet in height, and jointed together like a ruler at B. They are connected to each other by an iron round bar C, and wooden bar at the bottom D. The iron prongs EE fasten the uprights steadily to the edge of the cellar; F is the axis round which two ropes are coiled, the ends of which are fastened to the two clamps GG. On the axis F is fixed the iron wheel H, of 3 feet in diameter: in the teeth of this works the pinion I, of about 6 or 7 inches in diameter, and is turned by the handle at K.

It is evident, by a bare inspection of the figure, that when the two ropes are slipt over the ends upon the barrel, either at the top or bottom of the cellar, by turning of the winch K towards or from the operator, the barrel can be safely and expeditiously taken out or lowered down. When the crane is done with, it shuts up, by unscrewing the nut B, taking the wheel and axis away out of the loops at L, and folding the sides at A together, like a jointed rule; it may then be taken away in a cart or dray, or taken in the men's hands.

CENTRIFUGAL PUMP, a very curious machine, invented by Mr. Erskine, for raising water by means of a centrifugal force combined with the pressure of the atmosphere. It consists of a large tube of copper, &c. in the form of a cross, which is placed perpendicularly in the water, and rests at the bottom on a pivot. At the upper part of the tube is an horizontal cog-wheel, which touches the cogs of another in a vertical position; so that by the help of a double winch the whole machine is moved round with very great velocity. Near the bottom of the perpendicular part of the tube is a valve opening upwards; and near the two extremities, but on the contrary side of the arms or cross part of the tube, are two other valves opening outwards. These two valves are, by the assistance of springs, kept shut till the machine is put in motion, when the centrifugal velocity of the water forces them open, and discharges itself into a cistern or reservoir placed there for that purpose. On the upper part of the arms are two holes, which are closed by pieces screwed into the metal of the tube. Before

the machine can work, those holes must be opened, and water poured in through them, till the whole tube be full; by these means all the air will be forced out of the machine, and the water supported in the tube by means of the valve at the bottom. The tube being thus filled with water, and the holes closed by the screw-caps, it is turned round by means of the winch, when the water in the arms of the tube acquires a centrifugal force, opens the valves near the extremities of the arms, and flies out with a velocity nearly equal to that of the extremities of the said arms. The theory of this pump may be seen in arts. 537, 538, of our first volume.

CHUCK, UNIVERSAL. See TURNING.

CHURN, a well-known vessel in which butter, by long and violent agitation, is separated from the serous part of the milk.

The inferiority of the churns in common use has induced several ingenious mechanics to exert their skill in contriving others that would render the process of making butter less tedious and expensive. Of these, one of the most valuable is Mr. *William Bowler*'s improved churn, with which the Society for the Encouragement of Arts, &c. were so well satisfied as to present the inventor with thirty guineas. As it renders the operation of churning far less fatiguing, and has, besides, some peculiar advantages, we shall subjoin a description.

This churn is of the barrel kind, being a cylinder 18 inches in diameter, and 9 wide; the sides are of wood, and the rim a tin plate, which has two openings, one $8\frac{1}{2}$ inches in length, and 4 in width, through which the cream is poured into the churn, and the hand introduced for cleaning it; the other a short pipe, one inch in diameter, by which the butter-milk runs out of the churn when the operation is finished. The first of these openings has a wooden cover, fastened down by two screws; and the other a cork fitted to it, while the butter is churning. There is further, near the larger opening, a small vent-hole with a peg to admit the passage of any air that may be discharged from the cream at the beginning of the operation. An axle also passes through the churn, terminating in two gudgeons, on which it hangs; its lower part being immersed in a trough, in order to hold occasionally either hot or cold water, according to the season of the year. On the inside of the rim are four projecting pieces of wood, with holes serving to agitate the cream by the motion of the churn. The movement is caused by a pendulum 3 feet 6 inches long, that has an iron bob weighing 10lbs. and at its upper end a turning pulley 10 inches in diameter, from which a rope goes twice round another pulley about 3 inches in diameter fixed on the axis of the churn, which it causes to make a partial revolution by each vibration of the pendulum.

There are likewise sliding covers to the machinery, and another to the water trough; in order when hot water is used, to secure the steam, and keep the cream in a proper degree of warmth. The motion of the pendulum is given and continued, by means of a wooden rod about 3 feet 9 inches in length, which turns on a pin 3 inches above the bob of the pendulum. If there be a transverse handle at the upper end of this wooden rod, a boy may give motion to the churn with great facility, even while sitting; the action being then much like that of rowing, one of the most advantageous methods of applying human force.

AA, fig 8, pl. XII. is the body. B, an opening by which the cream is put on. C, the cover of the large opening: the small hole on the opposite side of the churn cannot be shown in this view. D, the gudgeon on which the body of the churn hangs. E, the upper or larger pulley. F, the smaller pulley fixed on the axis or gudgeon of the churn. GG, the rod of the pendulum hanging from the upper pulley E. H, the bob of the pendulum. II, the handle, moveable on a pin at *a*, by which the pendulum is moved to and fro, making a traverse in form of the dotted line KK. L, the trough for the hot or cold water. M, a projecting piece of wood, with a shoulder, by which the handle I is supported when the churn is not at work.

CLOCK, a machine now constructed in such a manner, and so regulated by the uniform motion of a pendulum, as to measure time, and all its subdivisions, with great exactness. Before the invention of the pendulum, a balance, not unlike the fly of a kitchen-jack, was used instead of it. Clocks were at first called nocturnal dials, to distinguish them from sun-dials, which showed the hour by the shadow of the sun.

The invention of clocks with wheels is ascribed to Pacificus, archdeacon of Verona, in the 9th century, on the credit of an epitaph quoted by Ughelli, and borrowed by him from Panvinius. Others attribute the invention to Boethius, about the year 510.

Mr. Derham, however, makes clock-work of a much older date; ranking Archimedes's sphere, mentioned by Claudian, and that of Posidonius, mentioned by Cicero, among machines of this kind; not that either their form or use was the same with those of ours, but that they had their motion from some hidden weights or springs, with wheels or pulleys, or some such clock-work principle.

In the *Disquisitiones Monasticæ* of Benedictus Haëften, published in the year 1644, he says, that clocks were invented by Silvester the 4th, a monk of his order, about the year 998, as Dithmarus and Bozius have shown; for before that time they

had nothing but sun-dials and clepsydræ to show the hour.—Conrade Gesner, in his Epitome, page 604, says, that Richard Wallingford, an English abbot of St. Alban's, who flourished in the year 1326, made a wonderful clock by a most excellent art, the like of which could not be produced by all Europe.—Moreri, under the word *Horologe* du Palais, says, that Charles the Fifth, called the wise, king of France, ordered at Paris the first large clock to be made by Henry de Vie, whom he sent for from Germany, and set it upon the tower of his palace in the year 1372.—John Froissart, in his *Histoire & Chronique*, vol. 2, chap. 28, says, the duke of Bourgogne had a clock which sounded the hour, taken away from the city of Courtray in the year 1382: and the same thing is said by William Paradin in his *Annals de Bourgogne.*

Clock-makers were first introduced into England in 1368, when Edward the Third granted a licence for three artists to come over from Delft, in Holland, and practise their occupation in this country.

The water-clocks or clepsydræ, and sun-dials, have both a much better claim to antiquity. The French annals mention one of the former kind, sent by Aaron, king of Persia, to Charlemagne, about the year 807, which it would seem bore some resemblance to the modern clocks: it was of brass, and showed the hours by 12 little balls of the same metal, which at the end of each hour fell upon a bell, and made a sound. There were also figures of 12 cavaliers, which at the end of each hour came out through certain apertures or windows in the side of the clock, and shut them again, &c.

The invention of pendulum clocks is owing to the happy industry of the 17th century; and the honour of that discovery is disputed between Galileo and Huygens. The latter, who wrote an excellent volume on the subject, declares it was first put in practice in the year 1657, and the description of it printed in 1658. Becher, *De Nova Temporis dimetiendi Theoria, anno* 1680, contends for Galileo; and relates, though at second-hand, the whole history of the invention; adding, that one Trefler, clock-maker to the father of the then grand-duke of Tuscany, made the first pendulum clock at Florence under the direction of Galileo Galilei, a pattern of which was brought to Holland. And the Academy del Cimento says expressly, that the application of the pendulum to the movement of a clock was first proposed by Galileo, and put in practice by his son Vincenzo Galilei in 1649. But whoever may have been the inventor, it is certain that the invention never flourished till it came into the hands of Huygens, who insists on it that, if ever Galileo thought of such a thing, he never brought it to any de-

gree of perfection. The first pendulum clock made in England was in the year 1662, by one Fromantil, a Dutchman.

After this brief sketch of the history of clocks, which may be interesting to some of our readers, we shall give a description of a modern clock according to the most approved construction. The first figure of plate VIII. is a profile of such a clock; P is a weight which is suspended by a cord that winds about the cylinder or barrel C, which is fixed upon the axis *a*, *a*; the pivots, *b*, *b*, go into holes made in the plates TS, TS, in which they turn freely. These plates are made of brass or iron, and are connected by means of *four* pillars, Z, Z; the whole together being called the *frame*. The weight P, if not restrained, would necessarily turn the barrel C, with an uniformily accelerating motion, in the same manner as if the weight were falling freely. But the barrel is furnished with a rachet-wheel, K, K, the right side of whose teeth strikes against the click, which is fixed with a screw to the wheel DD, as represented in fig. 2; so that the action of the weight is communicated to the wheel DD, the teeth of which act upon the teeth of the small wheel *d*, which turns upon the pivots *c*, *c*. The communication or action of one wheel with another is called the *pitching*; a small wheel like *d* is called a *pinion*, and its teeth are called *leaves* of the pinion. Several things are requisite to form a good pitching, the advantages of which are obvious in all machinery where teeth and pinions are employed. The teeth and pinion-leaves should be of a proper shape, and perfectly equal among themselves: the size also of the pinion should be of a just proportion to the wheel acting into it.

The wheel EE is fixed upon the axis of the pinion *d*; and the motion communicated to the wheel DD by the weight is transmitted to the pinion *d*, consequently to the wheel EE, as likewise to the pinion *e* and wheel FF, which moves the pinion *f*, upon the axis of which the crown or balance-wheel GH is fixed. The pivots of the pinion *f* play in holes of the plates LM, which are fixed horizontally to the plates TS. In a word, the motion begun by the weight is transmitted from the wheel GH to the palettes IK, and by means of the fork UX riveted on the palettes, communicates motion to the pendulum AB, which is suspended upon the hook A. The pendulum AB describes, round the point A, an arc of a circle alternately going and returning. If then the pendulum be once put in motion by a push of the hand, the weight of the pendulum at B will make it return upon itself, and it will continue to go alternately backward and forward till the resistance of the air upon the pendulum, and the friction at the point of suspension at A, destroys the original impressed force. But as at every vibration of the

pendulum the teeth of the balance-wheel GH act so upon the palettes IK (the pivots upon the axis of these palettes play in two holes of the potence *s t*), that after one tooth H has communicated motion to the pallete K, that tooth escapes; then the opposite tooth G acts upon the pallette I, and escapes in the same manner; and thus each tooth of the wheel escapes the palettes IK, after having communicated their motion to the palettes in such a manner that the pendulum, instead of being stopped, continues to move. The wheel EE revolves in an hour; the pivot *c* of this wheel passes through the plate, and is continued to *r*; upon the pivot is a wheel NN, with a long socket fastened in the centre; upon the extremity of this socket *r*, the minute-hand is fixed. The wheel NN acts upon the wheel O; the pinion of which *p* acts upon the wheel *gg*, fixed upon a socket which turns along with the wheel N. This wheel *gg* makes its revolution in 12 hours, upon the socket of which the hour-hand is fixed.

From the above description it is easy to see, 1. That the weight P turns all the wheels, and at the same time continues the motion of the pendulum. 2. That the quickness of the motion of the wheels is determined by that of the pendulum. 3. That the wheels point out the parts of time divided by the uniform motion of the pendulum.

When the cord upon which the weight is suspended is entirely run down from off the barrel, it is wound up again by means of a key, which goes on at the square end of the arbor at Q, by turning it in a contrary direction from that in which the weight descends. For this purpose the inclined side of the teeth of the wheel K (fig. 2.) removes the click C, so that the ratchet-wheel R turns while the wheel D is at rest; but as soon as the cord is wound up, the click falls in between the teeth of the wheel D, and the right side of the teeth again act upon the end of the click, which obliges the wheel D to turn along with the barrel; and the spring A keeps the click between the teeth of the ratchet-wheel R.

We shall now explain how time is measured by the motion of the pendulum; and how the wheel E, upon the axis of which the minute-hand is fixed, makes but one precise revolution in an hour. The vibrations of a pendulum are performed in a shorter or longer time in proportion to the length of the pendulum itself. A pendulum of $39\frac{1}{8}$ inches in length makes 3600 vibrations in an hour: *i. e.* each vibration is performed in a second of time, and for that reason it is called a *second pendulum.* But a pendulum of $9\frac{2}{3}\frac{5}{2}$ inches makes 7200 vibrations in an hour, or two vibrations in a second of time, and is called a *half-second pendulum.* Hence in constructing a wheel whose revolution

must be performed in a given time, the time of the vibrations of the pendulum which regulates its motion must be considered. Supposing, then, that the pendulum AB makes 7200 vibrations in an hour, let us consider how the wheel E shall take up an hour in making one revolution. This entirely depends on the number of teeth in the wheels and pinions. If the balance-wheel consists of 30 teeth, it will turn once in the time that the pendulum makes 60 vibrations: for at every turn of the wheel the same tooth acts once on the palette I, and once on the palette K, which occasions two separate vibrations in the pendulum; and the wheel having 30 teeth it occasions twice 30, or 60 vibrations. Consequently this wheel must perform 120 revolutions in an hour; because 60 vibrations, which it occasions at every revolution, are contained 120 times in 7200, the number of vibrations performed by the pendulum in an hour. Now, in order to determine the number of teeth for the wheels EF, and their pinions *ef*, it must be remarked that one revolution of the wheel E must turn the pinion *e* as many times as the number of teeth in the pinion is contained in the number of teeth in the wheel. Thus, if the wheel E contains 72 teeth, and the pinion *e* 6, the pinion will make 12 revolutions in the time that the wheel makes 1; for each tooth of the wheel drives forward a tooth of the pinion, and when the 6 teeth of the pinion are moved, a complete revolution is performed; but the wheel E has by that time only advanced 6 teeth, and has still 66 to advance before its revolution be completed, which will occasion 11 more revolutions of the pinion. For the same reason the wheel F having 60 teeth, and the pinion *f* 6, the pinion will make 10 revolutions while the wheel performs 1. Now, the wheel F being turned by the pinion *e* makes 12 revolutions for one of the wheel E; and the pinion *f* makes 10 revolutions for one of the wheel F; consequently the pinion *f* performs 10 times 12, or 120, revolutions in the time the wheel E performs one. But the wheel G, which is turned by the pinion *f*, occasions 60 vibrations in the pendulum each time it turns round; consequently the wheel G occasions 60 times 120, or 7200, vibrations of the pendulum while the wheel E performs but one revolution; but 7200 is the number of vibrations made by the pendulum in an hour, and consequently the wheel E performs but one revolution in an hour; and so of the rest.

From this reasoning it is easy to discover how a clock may be made to go for any length of time without being wound up. 1. By increasing the number of the teeth in the wheels. 2. By diminishing the number of teeth in the pinions. 3. By increasing the length of the cord that suspends the weight. 4. By increasing the length of the pendulum. And, 5. By adding to the

number of wheels and pinions. But in proportion as the time is augmented, if the weight continues the same, the force which it communicates to the last wheel GH will be diminished.

It only remains to take notice of the number of teeth in the wheels which turn the hour and minute-hands. The wheel E performs one revolution in an hour; the wheel NN, which is turned by the axis of the wheel E, must likewise make only one revolution in the same time; and the minute-hand is fixed to the socket of this wheel. The wheel N has 30 teeth, and acts upon the wheel O, which has likewise 30 teeth, and the same diameter; consequently the wheel O takes an hour to a revolution; now the wheel O carries the pinion *p*, which has 6 teeth, and which acts upon the wheel *qq* of 72 teeth; consequently the pinion *p* makes 12 revolutions while the wheel *qq* makes one, and of course the wheel *qq* takes 12 hours to one revolution; and upon the socket of this wheel the hourhand is fixed. Much that has been said here concerning revolutions of wheels, &c. is equally applicable to watches as to clocks.

But it is time to speak of the striking part; in which, indeed, as well as the other part of a clock, there is room for great variety and choice in the construction. The wheels usually composing this part are, the great or first wheel, which is moved by the weight or spring at the barrel, in sixteen or thirty-hour clocks; this has usually pins, and is called the *pin-wheel:* in eight-day pieces the second wheel is commonly the pin-wheel or striking-wheel, which is moved by the former. Next to the striking-wheel is the detent-wheel, or hoop-wheel, having a hoop almost round it, wherein is a vacancy at which the clock locks. The next is the third or fourth wheel, according to its distance from the rest, called the *warning-wheel.* The last is the flying pinion, with a fly or fan to gather air, and so bridle the rapidity of the clock's motion. To these must be added the pinion of report; which drives round the locking-wheel, called also the *count-wheel;* ordinarily with eleven notches in it, unequally distant, to make the clock strike the hours. Besides the wheels, to the clock part belongs the rash or ratch; a kind of wheel with twelve large fangs, running concentrical to the dial-wheel, and serving to lift up the detents every hour and make the clock strike: the detents or stops, which being lifted up and let fall, lock and unlock the clock in striking; the hammer, which strikes the bell; the hammer tails, by which the striking pins draw back the hammers; latches, whereby the work is lifted up and unlocked; and lifting-pieces, which lift up and unlock the detents.

In the year 1803 the Society for the Encouragement of Arts, &c. assigned to Mr. John Prior of Nessfield, Yorkshire, a

reward of 30 guineas, on account of his contrivance for the *striking* part of an eight-day clock. As this invention is likely to be useful, we shall describe it here. It consists of a wheel and fly, with six turns of a spiral line, cut upon the wheel for the purpose of counting the hours. The pins below this spiral elevate the hammer, and those above are for the use of the detent. This single wheel serves the purpose of count-wheel, pin-wheel, detent-wheel, and the fly-wheel, and has six revolutions in striking the 12 hours. If we suppose a train of wheels and pinions used in other striking parts to be made without error, and that the wheels and pinions would turn each other without shake or play; then, allowing the above supposition to be true (though every mechanic knows it is not), Mr. Prior's striking part would be found six times superior to others, in striking the hours 1, 2, 5, 7, 10, 11; twelve times superior in striking 4, 6, 8; and eighteen times, in striking 3, 9, and 12. In striking 2, the inventor purposely made an imperfection equal to the space of three teeth of the wheel; and, in striking 3, an imperfection of nine or ten teeth; and yet both these hours are struck perfectly correct. The flies in clocks turn round, at a mean, about sixty times for every knock of the hammer, but this turns round only three times for the same purpose; and suppose the pivots were of equal diameters, the influence of oil on them would be as the number of revolutions in each. It would be better for clocks if they gave no warning at all, but the snail-piece to raise a weight somewhat similar to the model Mr. P. sent for the inspection of that respectable Society.

Reference to MR. PRIOR's *Striking Part of his Clock.*

Plate X. fig. 1.—A, the large wheel, on the face of which are sunk or cut the six turns of a spiral.

B, the single worm screw, which acts on the above wheel, and moves the fly C.

D, the spiral work of the wheel A. The black spots show the grooves into which the detents drop on striking the hour.

E, the groove into which the locking-piece F drops when it strikes one, and from which place it proceeds to the outward parts of the spiral in the progressive hours, being thrown out by a lifting piece H at each hour: the upper detent G being pumped off with the locking-piece F, from the pins in the wheel A.

In striking the hour of *twelve*, the locking-piece, having arrived at the outer spiral at H, rises up an inclined plane, and drops by its own weight to the inner circle, in which the hour *one* is to be struck, and proceeds on in a progressive motion through the different hours till it comes again to *twelve*.

I, the hammer-work made in the common way, which is worked by thirteen pins on the face of the spiral.

Fig. 2.—K, the thirteen pins on the face of the spiral, which work the hammer-work.

L, the outer pins, which lock the detent.

M, the pump-spring to the detent.

For other information respecting clock-work, see the articles BALANCE, PENDULUM, and SCAPEMENT, in this volume.

Some very simple contrivances for clocks, by Mr. Ferguson, and Dr. Franklin, may be seen in *Ferguson's Select Exercises.*

In the fourth century an artist named James Dondi constructed a clock for the city of Padua, which was long considered as the wonder of that period. Besides indicating the hours, it represented the motion of the sun, moon, and planets, as well as pointed out the different festivals of the year. On this account Dondi obtained the surname of Horologio, which became that of his posterity. A little time after, William Zelander constructed for the same city a clock still more complex; which was repaired in the sixteenth century by Janellus Turrianus, the mechanist of Charles V.

But the clocks of the cathedrals of Strasburgh and of Lyons are much more celebrated. That of Strasburgh was the work of Conrad Dasypodius, a mathematician of that city, who finished it about 1573. The face of the basement of this clock exhibits three dial-plates; one of which is round, and consists of several concentric circles; the two interior ones of which perform their revolutions in a year, and serve to mark the days of the year, the festivals and other circumstances of the calendar. The two lateral dial-plates are square, and serve to indicate the eclipses both of the sun and the moon. Above the middle dial-plate, and in the attic space of the basement, the days of the week are represented by different divinities supposed to preside over the planets from which their common appellations are derived. The divinity of the current day appears in a car rolling over the clouds, and at midnight retires to give place to the succeeding one. Before the basement is seen a globe, borne on the wings of a pelican, around which the sun and moon revolved; and which in that manner represented the motion of these planets: but this part of the machine, as well as several others, has been deranged for a long time. The ornamental turret, above this basement, exhibits chiefly a large dial in the form of an astrolabe; which shows the annual motion of the sun and moon through the ecliptic, the hours of the day, &c. The phases of the moon are seen also marked out on a particular dial-plate above. This work is remarkable also for a considerable assemblage of bells and figures, which perform different motions.

Above the dial-plate last mentioned, for example, the four ages of man are represented by symbolical figures: one passes every quarter of an hour, and marks the quarter by striking on small bells; these figures are followed by Death, who is expelled by Jesus Christ risen from the grave: who, however, permits it to sound the hour, in order to warn man that time is on the wing. Two small angels perform movements also; one striking a bell with a sceptre, while the other turns an hour-glass at the expiration of an hour. In the last place, this work was decorated with various animals, which emitted sounds similar to their natural voices; but none of them now remains except the cock, which crows immediately before the hour strikes, first stretching out its neck and clapping its wings. Indeed it is to be regretted that a great part of this machine is now entirely deranged.

The clock of the cathedral of Lyons is of less size than that of Strasburgh, but is not inferior to it in the variety of its movements; it has the advantage also of being in a good condition. It is the work of Lippius de Basle, and was exceedingly well repaired in the last century by an ingenious clock-maker of Lyons, named Nourisson. Like that of Strasburgh, it exhibits on different dial-plates the annual and diurnal progress of the sun and moon, the days of the year, their length, and the whole calendar, civil as well as ecclesiastic. The days of the week are indicated by symbols more analogous to the place where the clock is erected: the hours are announced by the crowing of a cock, three times repeated after it has clapped its wings and made various other movements. When the cock has done crowing, angels appear, who, by striking various bells, perform the air of a hymn; the annunciation of the Virgin is represented also by moving figures, and by the descent of a dove from the clouds; and after this mechanical exhibition the hour strikes. On one of the sides of the clock is seen an oval dial-plate, where the hours and minutes are indicated by means of an index, which lengthens or contracts itself, according to the length of the semi-diameter of the ellipsis over which it moves.

A very curious clock, the work of Martinot, a celebrated clock-maker of the seventeenth century, was formerly to be seen in the royal apartments at Versailles. Before it struck the hour, two cocks on the corners of a small edifice crowed alternately, clapping their wings: soon after two lateral doors of the edifice opened, at which appeared two figures bearing cymbals, beat upon by a kind of guards with clubs. When these figures had retired, the centre door was thrown open, and a pedestal, supporting an equestrian statue of Lewis XIV. issued from it, while a group of clouds separating, gave a passage to a figure of Fame, which came and hovered over the statue. An air was

then performed by bells: after which the two figures re-entered; the two guards raised up their clubs, which they had lowered as if out of respect for the presence of the king, and the hour was then struck.

While, however, we have thought it right to describe these ingenious performances of foreign artists, we must not neglect to mention the equally ingenious workmanship of some of our own countrymen. We now refer to two clocks made by English artists, as a present from the East-India Company to the emperor of China. These two clocks are in the form of chariots, in each of which a lady is placed in a fine attitude, leaning her right hand upon a part of the chariot, under which appears a clock of curious workmanship, little larger than a shilling, that strikes and repeats, and goes for eight days. Upon the lady's finger sits a bird, finely modelled, and set with diamonds and rubies, with its wings expanded in a flying posture, and actually flutters for a considerable time on touching a diamond button below it: the body of the bird, in which are contained part of the wheels that animate it as it were, is less than the 16th part of an inch. The lady holds in her left hand a golden tube little thicker than a large pin, on the top of which is a small round box, to which is fixed a circular ornament not larger than a sixpence, set with diamonds, which goes round in near three hours in a constant regular motion. Over the lady's head is a double umbrella, supported by a small fluted pillar not thicker than a quill, and under the larger of which a bell is fixed, at a considerable distance from the clock, with which it seems to have no connexion; but from which a communication is secretly conveyed to a hammer, that regularly strikes the hour, and repeats the same at pleasure, by touching a diamond button fixed to the clock below. At the feet of the lady is a golden dog.

COINAGE, or Coining, the art or act of making money.

Coining is either performed by the hammer or the mill. The first method is now little used in Europe, especially in England, France, &c. though the only one known till the year 1553, when a new machine, or coining-mill, invented by an engraver, one Antoine Brucher, was first tried in the French king's palace at Paris, for the coining of counters: though some attribute the invention of the mill to Varin, a famous engraver, who, in reality, was no more than an improver of it; and others to Aubrey Olivier, who had only the inspection of it.

The mill has met with various fate since its first invention; being now used, and again laid by, and the hammer resumed: but it has at length got that footing, by the neatness and per-

fection of the species struck with it, that there appears no great probability of its ever being again disused.

In either kind of coining, the pieces of metal are stamped or struck with a sort of punchions or dyes, wherein are engraven the prince's effigies, with the arms, legends, &c.

Coining by the mill, or milled money.—The bars or plates being taken out of the mould, and scraped and brushed, are passed several times through a mill, to flatten them further, and bring them to the just thickness of the species to be coined; with this difference, however, that the plates of gold are heated again in a furnace, and quenched in water, before they undergo the mill; which softens and renders them more ductile: whereas those of silver pass the mill just as they are, without any heating; and when afterwards they are heated, they are left to cool again of themselves, without water.

The plates, whether gold, silver, or copper, thus reduced as near as possible to their thickness, are cut into round pieces, called blanks or planchets, near the size of the intended species, with a cutting instrument fastened to the lower extremity of an arbor, whose upper end is formed into a screw; which, being turned by an iron handle, turns the arbor, and lets the steel, well sharpened, in form of a punch-cutter, fall on the plates; and thus is a piece punched out.

These pieces are now given to be adjusted, and brought by filing, or rasping, to the weight of the standard, whereby they are to be regulated: and what remains of the plate between the circles is melted again, under the denomination of sizel.

The pieces are adjusted in a fine balance: and those which prove too light are separated from those too heavy; the first to be melted again, and the second to be filed down. For it may be observed, that the mill through which the plates are passed can never be so just but there will be some inequality, whence will arise a difference in the blanks. And this inequality, indeed, may be owing to the quality of the matter as well as of the machine; some parts being more porous than others.

When the blanks are adjusted they are carried to the blanching or whitening-house, i. e. the place where the gold blanks have their colour given them, and the silver ones are whitened; which is done by heating them in the furnace, and, when taken out and cooled, boiling them successively in two copper vessels, with water, common salt, and tartar: and, after that, scouring them well with sand, and washing them with common water, drying them over a wood fire, in a copper sieve, wherein they are put when taken out of the boilers.

Formerly the planchets, as soon as blanched, were carried

to the press, to be struck, and receive their impressions; but now they are first marked with letters or graining on the edges, to prevent the clipping and paring of the species, which is one of the ways wherein the ancient money used to be damaged. The machine used to mark the edges is very simple, yet ingenious; it consists of two plates of steel, in form of rulers, about the thickness of a line, on which the legend or edging is engraven, half on the one, and half on the other. One of these plates is immoveable, being strongly bound with screws to a copper plate; and that again to a strong board, or table: the other is moveable, and slides on the copper plate by means of a handle, and a wheel, or pinion of iron, the teeth whereof catch in a kind of other teeth, on the surface of the sliding plate. Now, the planchet, being placed horizontally between these two plates, is carried along by the motion of the moveable one; so as by that time it has made half a turn, it is found marked all round. See fig. 1. pl. XIV.

This machine is so easy, that a single man is able to mark twenty thousand planchets in a day. Savang pretends it was invented by the Sieur Castagin, engineer to the French king, and first used in 1685. But it is certain we had the art of lettering the edges in England long before that time; witness the crowns and half-crowns of Oliver Cromwell struck in 1658, which for beauty and perfection far exceed any French coins we have ever seen.

Lastly, the planchets, being thus edged, are to be stamped, i. e. their impression is to be given them in a sort of mill, or press, by the French called a balancier, invented towards the latter end of the sixteenth century. See its figure in fig. 2. pl. XIV.

Its chief parts are a beam, screw, arbor, &c. all contained in the body of the machine, except the first, which is a long iron bar, with a heavy ball of lead at each end, and rings, to which are fastened cords, which give it motion: this is placed horizontally over the body of the machine. In the middle of the beam is fastened a screw, which, by turning the beam, serves to press the arbor underneath it; to the lower extremity of which arbor, placed perpendicularly, is fastened the dye, or matrice, of the reverse, or arm side, in a kind of box, or case, wherein it is retained by screws: and under this is a box, or case, containing the dye of the image-side, firmly fastened to the lower part of the engine, fig. 3.

Now, when a planchet is to be stamped, it is laid on the image-matrice, upon which two men draw, each on his side, one of the ropes of the beam, and turn the screw fastened in it; which by this motion lowers the arbor to which the dye of

the arms is fastened: by which means the metal, being in the middle, at once receives an impression on each side, from either dye. As to the press formerly used, it has all the essential parts of a balancier, except the beam, which is here, as it were, divided, and only drawn one way.

The blanks having now all their marks and impressions, both on the edges and faces, become money; but they have not currency till they have been weighed and examined.

For the Coining of Medals, the progress is the same, in effect, with that of money: the principal difference consists in this, that money, having but a small relievo, receives its impression at a single stroke of the engine; whereas, for medals, the height of their relievo makes it necessary that the stroke be repeated several times: to this end the piece is taken out from between the dyes, heated, and returned again; which process, in medallions and large medals, is sometimes repeated fifteen or twenty times, before the full impression be given; care being taken, every time the planchet is removed, to take off the superfluous metal stretched beyond the circumference, with a file.

An improvement has been lately suggested in the coining-press, by a Mr. Huigenan, we believe, who has introduced the principle of the heart-wheel both in this contrivance and in his universal lever. The method Mr. H. recommends may be understood by referring to fig. 4. pl. XIV. CB is part of a table or plane, on which is fixed the box containing the dye F of the image side of the coin, and CA is a lever, to which is attached the dye E of the reverse side in a case retained by screws; and this is so posited, that by turning CA on the centre C, the parts E and F may be brought the one immediately above the other. G is an elliptical or heart-wheel turning upon a fixed centre by the handle or winch H, and, acting upon the friction-wheel D, gradually forces down the end A of the lever, and carries with it the dye E, causing it to press very hard upon the metal placed on the lower dye F, at the time the extremity I of the elliptical wheel is in contact with the upper part of the wheel D. Then the motion of the winch proceeding, the spring S raises up the lever CA, and thus leaves room to remove the metal: place another at F, and repeat the operation. The whole, it is obvious, may be carried on with considerable expedition; but whether the method is on the whole preferable to that before described, is what we do not here attempt to decide.

In the machinery invented for coining by Boulton and Watt, and lately introduced in the Mint, the screw presses for cutting out the circular pieces of metal are worked with great

facility, and both the edges and the faces of the money are coined at the same time, with such superior excellence and cheapness of workmanship as will prevent clandestine imitation. By means of this machinery four boys can strike 30,000 pieces of money in an hour: the machine has this farther advantage, that it serves as a register, and keeps an unerring account of the number of pieces struck. An interesting description of the principal parts of this machinery, with diagrams, may be seen in the *Mechanic's Magazine*, Nos. 62 to 67, inclusive.

COMPASSES (BEAM), a kind of compasses used to draw large arcs, and to take large extents, &c. These compasses consist of a straight beam or bar, of 18 inches, 2 feet or more in length, carrying two brass cursors; one of these being fixed at one end, the other sliding along the beam, with a screw to fasten it on occasionally. To the cursors may be screwed points of any kind, as of steel, brass, pencils, &c. The fixed cursor has sometimes an adjusting or micrometer screw applied to it, for the more nice obtaining of extents.

The beam is divided commonly into inches, tenths, and half tenths: but Mr. Walton, an ingenious mechanic, in the proof department of the Royal Arsenal, Woolwich, has improved this instrument, and much extended its utility, by applying a nonius to its scale, which renders it fit to take distances to hundredth parts of an inch. Part of a beam with the additions of Mr. Walton are shown in fig. 1. pl. XVIII. where IK represents more than 4 inches in length of a beam, which is made of ebony, the divisions being marked upon brass laid into the ebony. ABCD and EFGH are two brass cases which nearly fit the beam, and may slide to and fro upon it: these brass cases carry the cursors and points L and M, which are fastened into sockets by means of screws at N and O. The case ABCD has two screws *bc* and *a*, both of which are turned by means of forked turn screws: the first of these screws, *bc*, serves to move the brass case backwards and forwards on the beam, in order to adjust the point L so as to correspond with the commencement of the divisions on the beam; and when that is done, the screw *a*, by pressing a spring, makes the whole fast to the beam. The other brass case EFGH carries the cursor and point M, as well as the moveable nonius *ei*: this nonius is at the extremity of a piece *efghki*, which is moved to and fro upon the case EFGH by means of the screw *opqs*, which is turned by the milled head *rst*: the shoulders at *p* and *q* prevent the screw from moving either backward or forward with respect to the line FH, while the threads of the screw between *o* and *p*, by taking upon the moveable piece

efghki, cause the nonius to move along the edge of the graduated scale of the beam: turning the head of the screw in the direction *rst* moves the nonius in the direction from K towards I on the beam; and turning that head in the direction *tsr* advances the nonius according to the increasing measure upon the scale from I towards K. The screw *d*, with its milled head P, by pressing upon a spring, will at any time make the case EFGH fast to the beam, and thus prevent, when necessary, any change of distance between L and M. Fig. 2. is a transverse section of the brass case EFGH: it serves to show the form 1, 2, 3, 4, 5, of the beam, bevelled off to an edge at 4; also the bevel of the nonius at *e*; the dovetail at *q*, against which one shoulder of the micrometer screw presses; and the piece *fv*, into which the three screws *l, m, n* (fig. 1.) enter. Other parts of the construction will be sufficiently obvious from these figures.

CONDENSER, a pneumatic engine or syringe, by which an extraordinary quantity of air may be crowded or pushed into a given space; so that frequently ten times as much air as an equal space would contain out of the engine may be thrown in by means of it, and its egress prevented by valves properly disposed.

The condenser is made either of metal or of glass, and either in a cylindrical or globular form; and the air is forced into it by an injecting syringe. The receiver or vessel containing the condensed air should be made very strong, to bear the force of the air's elasticity thus increased: for which reason it is commonly made of brass. When glass is used it will not sustain so great a condensation of air; but the experiment will, notwithstanding, be rendered more entertaining, as the effect of the condensed air upon any subject put within the receiver may be viewed through the glass.

CONDENSER *of Forces*, a name given by M. Prony to a contrivance for obtaining the greatest possible effect from a first mover, the energy of which is subject to augmentation or diminution within certain limits; and in general to vary at pleasure the resistance to which the effort of the first mover forms an equilibrium in any machine whatever, without changing any part of their construction.

The general problem in mechanics, of which this condenser is intended as a practical solution, is enunciated by M. Prony in these terms:

"Any machine being constructed, to find, without making any change in the construction, a means of transmitting to it the action of the first mover, by fulfilling the following conditions, viz.

"1. That it may be possible at pleasure, and with great speed and facility, to vary the resistance (against which the efforts of the first mover must continually make an equilibrium) in limits of any required extent.

"2 That the resistance, being once regulated, shall be rigorously constant until the moment when it is thought proper to increase or diminish the same.

"3. That in the most sudden variations of which the effort of the first mover may be capable, the variation in velocity of the machine shall never undergo a solution of continuity."

M. Prony applies his solution of this problem to the dynamic effect of wind: it will be easy to make the same general when the other first movers are used.

The section and plan of the machine are exhibited in pl. XIV. oo represents the vertical arbor to which windmill sails are adapted; *eeee* is an assemblage of carpentry, of which one of the radii, o*e*, bears a curved piece *bd*, of iron or steel: vertical axes of rotation *aaa*, being placed round the axis oo, also divide the circumference in which they are found into equal parts.

Each of these axes carries a curve, *af*, of iron, steel, or copper, so situated, that when the wind acts upon the sails the curve *bd* presses against one of the curves *af*, and causes the vertical axis to which this last curve is fixed to make a portion of a revolution.

The curves *bd* and *af* must be so disposed, that when *bd* ceases to press on one of the curves *af*, it shall at the same instant begin to act upon the following curve: the number of axes which are provided with these curves must be determined by the particular circumstances of each case; and it is also practicable to substitute, instead of *bd*, a portion of a toothed wheel having its centre at the axis oo, and to place portions of pinions instead of the curves *af*; but the dispositions represented in the figure are preferable.

Each of these axes *aaaa* (which are all fitted up alike, though, for the sake of clearness, only one of them has its apparatus represented in the drawing), carries upon it a drum or pulley *ttrr*, on which is wound a cord that passes over a pulley *p*, and serves to support a weight Q by means of the lever FG, upon which this weight may be slided and fastened at different distances from the point of motion G.

The same axes *aa* pass through the pinions *qq*, to which they are not fixed; but these pinions carry clicks or ratchets, which bear against the teeth *rr*; so that, when the weight Q tends to rise, the ratchet gives way, and no other effect is produced on the pinion *qq*, either by the motion of the axis or of

the drum *ttrr*, excepting that which causes the ascent of the weight *qq*. But the instant that the curve or tooth *bd* ceases to bear against one of the curves *af*, after having caused the corresponding weight Q to rise, that weight Q tends to redescend, and then the toothed wheel *rr* acts against the ratchet, so that Q cannot descend without turning the pinion *qq* along with the drum *ttrr*.

The pinion *qq* takes in the wheel *ab*, from the motion of which the useful effect of the machine immediately results; so that the effect of the descent of one of the weights Q is to solicit the wheel AB to motion, or to continue the motion in concurrence with all the other weights Q, which descend at the same time. This wheel AB carries beneath it oblique or bevelled teeth GD, which take in a like wheel CE, and cause the buckets at S to rise.

From the preceding description it is seen that the machine, being supposed to start from a state of repose, the wind will at first raise a number of weights Q, sufficient to put the machine into motion, and will continue to raise new weights while those before raised are fallen; so that the motion once impressed will be continued.

Among the numerous advantages of this new mechanism we may remark the following:

1. No violent shock can take place in any part of the mechanism.

2. The useful effect being proportioned to the number of weights Q, which descend at the same time, this effect will increase in proportion as the wind becomes stronger, and causes the sails to turn with more velocity.

3. The weights Q being moveable along the levers FG, it will always be very easy to place them in such a manner as to obtain that ratio of the effort of the first mover to the resistance which will produce the maximum of effect.

4. From this property it results that advantage may be taken of the weakest breezes of wind, and to obtain a certain product in circumstances under which all other windmills are in a state of absolute inactivity. This advantage is of great importance, particularly with regard to agriculture: the windmills employed for watering lands are sometimes inactive for several days, and this inconvenience is more particularly felt in times of drought. A machine capable of moving with the slightest breeze must therefore offer the most valuable advantages.

CRAB or GIN, an engine used for mounting large guns on their carriages, &c. It is composed of three long and stout legs meeting together at their tops; these legs are round poles of about 12 or 13 feet long, whose diameters at the lower ends

are about four inches, five just below the roller, besides the cheeks that are added to them in that place, and about $3\frac{1}{2}$ inches above.

Two of these poles can be fixed at a certain distance from each other, by means of two iron bars placed horizontally, one being about four feet long, the other about seven; and a roller is made to run upon pivots turning on, or in, these two poles: this roller is commonly $7\frac{3}{4}$ inches in diameter, and six feet long. A portion of 20 inches is left square at each end, and holes made in each to receive the handspikes by which the men turn the roller: but the middle part is made cylindrical, to wind the cable upon. The transverse iron bars are fixed with one end to one of the poles by means of a bolt, and with the other end to the other pole with a bolt and key; so as to be readily taken out, in order that when the gin is to be removed from place to place the poles may lie close together upon the carriage. There are two iron bands and two iron bolts to fasten each cheek (for the pivots) to the poles, and iron plates round the poles where the iron bars are fixed. The poles are hooped at each end; and the upper ends have straps through which an iron bolt passes: this bolt keeps the upper ends together, as well as serves to support the iron to which the windlass is hooked. The windlass contains two brass pulleys, about which the cable goes, which is fixed to the dolphins of the gun or mortar with another windlass, containing two brass pulleys likewise. When this machine is used the whole is laid flat on the ground, the lower end of the single pole extending the contrary way, in order to fasten the upper windlass after the cable has been turned round both: after this the upper end is raised gradually till the feet of the three poles (each of which has an iron prong) stand nearly at equal distances; in such a manner as the legs of a theodolite or plain table, when set up for use in the practice of surveying.

CRANE, a machine used in building, on wharfs, and in warehouses, for raising and lowering huge stones, ponderous weights, packages, &c.

1. Cranes, until of late years, were commonly constructed as follows: the principal member is a strong upright beam or arbor, firmly fixed in the ground, and sustained by eight arms, coming from the extremities of four pieces of wood laid across, through the middle of which passes the foot of the beam. About the middle of the arbor the arms meet, and are mortised into it: its top ends in an iron pivot, on which is borne a transverse piece, advancing out to a good distance, something after the manner of a crane's neck, whence the machine has its name. This projecting piece is now more commonly called the jib or

gibbet. The middle and extremities of this are again sustained by arms from the middle of the arbor: and over it comes a rope or cable, to one end of which the weight is fixed; the other is wound about the spindle of a wheel, which when turned (commonly by means of men walking upon the inside of the rim of the wheel) draws the rope, and that heaves up the weight; which may afterwards be applied to any side or quarter by the mobility of the transverse piece on the pivot. These cranes have usually been made of two kinds: in the first, called the rat-tailed crane, the whole machine with the load turns upon a strong axis: in the second kind the gibbet alone moves on its axis. But in either kind, if the machinery be put into motion by men walking *within* the wheel, as has been till lately the nearly universal practice in this country, the labourers employed are exposed to extreme danger, and have frequently met with the most shocking and fatal accidents. It is not then to be wondered at, that skilful mechanists should at length have devised cranes that are not only more safe, but more powerful in their operation, than the common walking crane: a few of the best of these will be described in the present article.

2. The late Mr. Ferguson invented a crane which has three trundles, with different numbers of staves, that may be applied to the cogs of a horizontal wheel with an upright axle; round which is coiled the rope that draws up the weight. This wheel has 96 cogs; the largest trundle 24 staves, the next 12, and the smallest 6, so that the largest revolves 4 times for one revolution of the wheel; the next 8, and the smallest 16. A winch is occasionally fixed on the axis of either of these trundles for turning it, and is applied to the one or the other according as the weight to be raised is smaller or larger. While this is drawing up, the ratch-teeth of a wheel slip round below a catch that falls into them, prevents the crane from turning backwards, and detains the weight in any part of its ascent, if the man who works at the winch should accidentally quit his hold, or wish to rest himself before the weight is completely raised. Making a due allowance for friction, a man may raise by such a crane from three times to twelve times as much in weight as would balance his effort at the winch; viz. from 90 to 360lbs., taking the average labour.

Other ingenious contrivances by Mr. Ferguson may be seen in his *Select Exercises;* but as the book is in the hands of almost every practical mechanic, we would rather refer to it than extract accounts of these inventions.

3. The crane presented in pl. VII. is a portable one, mounted in a wooden frame and stage, which is judged to be very useful for loading and unloading carts with large heavy stones. It is

moveable to any part of a stone-yard or ground; the frame is sufficiently wide for a cart to draw under the crane, and at any time it may be taken to pieces. The frame AAAA is made of wood, is about 9 or 10 feet high, and about 9 feet square. The wheels BB are of iron, and are about 3 feet in diameter; and the pinion D, that is fixed to the axis of the first wheel B, 8 inches in diameter: on the axis of the second wheel B the axis round which the rope coils is fixed. Now the stones being corded and hooked at the end of the rope, it is very evident that the man at C will either raise or lower them as may be necessary, according as he turns the winch towards or from him, and in a safe and very easy manner. The advantage in point of power being in proportion as the product of the radii of the wheels to those of the pinions.

4. Fig. 7. pl. XII. is a representation of a crane-carriage which Mr. Gottlieb conceives to be very useful in moving large stones in quarries, where carts and horses cannot be conveniently or at all managed. Its principle is evident from a bare view of the figure. It consists only of two sets of crane-wheels applied to the two sets of wheels belonging to the carriage; so that two men, one at each winch AA, turning the pinions and wheels round, shall act upon the carriage-wheels and move it along. By their both turning forwards or backwards, the carriage goes accordingly; but if they turn contrary ways, the carriage will be turned round, or partly so, as may be wanted. The pinion B is 6 inches in diameter, which turns the wheel C of 3 feet diameter, on the axis of which is fixed the pinion D of 1 foot diameter, which works into two wheels E, E, of 3 feet 6 inches diameter, that are fixed upon the carriage-wheels, and give motion to the whole machine.

5. Mr. *Abraham Andrews*, of Higham Ferrers, in Northamptonshire, has invented a crane which weighs the body suspended at the time it is raising: an improvement for which the Society for the Encouragement of Arts, &c. granted him a premium of 15 guineas. This crane is shown in fig. 3. pl. IX. The jib of the crane stands on a horizontal beam, moveable on a centre at A: and the distance of the centre A, from the bearing of the upright, being to the distance B, in proportion of 1 to 20, the weight placed at B determines that of the body suspended in the same proportion. C is a stub, or piece of wood, which projects from the weight hanging at the end of the jib, and serves to prevent the beam from rising to too great a height.

This jib should be placed in the same vertical plane with the part BA of the crane, at the time the weight is adjusted; otherwise it will occasion a friction which may prevent the moveable beam from playing freely. The other parts of the crane are so

obvious in their construction as not to require a more minute description.

6. The society just mentioned have lately voted 40 guineas to Mr. *Robert Hall*, jun. of Basford, near Nottingham, for his ingenious invention of a method to expand a set of bars parallel to the axis of a crane, by which means the velocity of the rope in raising weights may be increased or diminished in proportion to the load to be raised.

A description and engraving of this crane are given in the twelfth volume of the Society's Transactions, from which we have drawn up the following account of it:

The ends of the reel (fig 1. and 5. pl. XIII.) consist each of two flat plates or circular pieces, shown separately in fig. 2. and 3. These circular plates form the two ends of the reel, and are held fast on the spindle or axis by pins passed through its ends, of which one may be seen at *a*, fig. 2. and another in the end shown in fig. 5. The outer circular plate (fig. 3) of each end of the reel has a spiral groove cut in it, as shown at *b*; and the inner circles have each eight mortices cut quite through them, as shown at *c*. fig. 2. (seen partly also in fig. 1. and 5.). The outer plates have also an iron tube, *d*, made fast to them by means of a flange or collar, and the screws *ce*, fig. 2.

When the parts are all joined (as shown in fig. 1.), the axis *f* passes through the tube *d*, and thus the ends are connected. In fixing the cross bars, two of which are shown detached in fig. 4., the parts *gg* slide in the mortices *c* of the inner circular plates, and the small ends or tenons *hh* go fairly through the inner and enter the spiral grooves of the outer plates.

The inner and outer circular plates are locked together by a catch (*i*, fig. 1. 2. and 6.) the stationary part of which is made fast to the inner plate (see fig. 2.), while the catch itself, by means of a spring, is kept in a notch on the edge of the outer plate. When the diameter of the reel is to be enlarged or diminished, it is effected by bringing the reel round to the position shown in fig. 6, when a hook *k* is put into a hole *l*, which keeps the inner circular plate in that position till the adjustment is made by lifting the catch from the notch of the outer end-plate far enough to be kept disengaged by the hook *k*, before mentioned, being thrust quite through the hole *l*: the handle *m* being then turned, the outer plate only is carried round, and the tenons or small ends of the cross bars (being prevented from being carried round with it, by the mortices of the inner plates through which they pass being stationary) are obliged to change their distance from the axis by the spiral groove sliding over them, while they are able to move nearer or fur-

ther from the axis by sliding in radial mortices of the inner end plate.

The handle *m* being turned till the reel is of the size required, the hook *k* is withdrawn or pushed out, and the crane is then ready for work.

It is necessary to observe that the tenons *hh* must be cut, so that the outside of all the bars next the rope shall be at an equal distance from the centre. If the tenon of the first bar that is placed in the reel be cut like the tenons *hh*, fig. 4. the last of them must be cut the same as the tenons *nn*, fig. 4.; and all the other tenons, at the extremities of the several bars, must be at proper distances between these extremes, as is shown by the dots P in the mortices fig. 2.

The other parts of the crane may be so easily understood from an inspection of the engraving, that any further description is unnecessary. (*Phil. Mag.* No. 71.)

7. But the several cranes described in this article as preferable to the common walking-crane, while they are free from the dangers attending that machine lose at the same time one of its advantages; that is, they do not avail themselves of that addition to the moving power which the *weight* of the men who are employed may furnish. Yet this advantage has been long since ensured by the mechanists on the continent, who cause the labourers to walk upon an inclined plane, turning upon an axis, after the manner shown in the figure referred to under the article *Footmill*, where we have described a contrivance of that kind, well-known in Germany full 170 years ago. The same principle has been lately brought into notice, probably without knowing it had ever been adopted before, by Mr. *James Whyte*, of Chevening, in Kent: his crane is exhibited in fig. 3. and 4. pl. X. as it was described in the Transactions of the Society for the Encouragement of Arts.

A (fig. 3.) is a circular inclined plane, moving on a pivot underneath it, and carrying round with it the axis E. A person walking on this plane, and pressing against the lever B, throws off the gripe D, by means of an iron rod C; and thus admits the plane and its axis to move freely, and raise the weight G by the coiling of the rope F round the axis E.

To show more clearly the construction and action of the lever and gripe, a plan of the circular inclined plane, with the lever and gripe, is added (see fig. 4.), where B represents the lever, D the spring or gripe. In this plan, when the lever B is in the situation in which it now appears, the spring or gripe D presses against the periphery of the plane, as shown by the double line; and the machine cannot move; but when the lever B is pressed out to the dotted line H the gripe is also thrown off to the

dotted line 1, and the whole machine left at liberty to move. One end of a rope or cord, of a proper length, is fixed near the end of the lever B, and the other end made fast to one of the uprights, serving to prevent the lever moving too far when pressed by the man.

The supposed properties of this crane, for which the premium of 40 guineas was adjudged by the society to the inventor, are as follow:

1. It is simple, consisting merely of a wheel and axle. 2. It has comparatively little friction, as is obvious from the bare inspection of the figure. 3. It is durable, as is evident from the two properties above-mentioned. 4. It is safe; for it cannot move but during the pleasure of a man, and while he is actually pressing on the gripe-lever. 5. This crane admits of an almost infinite variety of different powers, and this variation is obtained without the least alteration of any part of the machine. If, in unloading a vessel, there should be found goods of every weight, from a few hundreds to a ton and upwards, the man that does the work will be able so to adapt his strength to each as to raise it in a space of time proportionate to its weight; he walking always with the same velocity as nature and his greatest ease may teach him.

It is a great disadvantage in some cranes, that they take as long time to raise the smallest as the largest weight, unless the man who works them turn or walk with such velocity as must soon tire him. In other cranes, perhaps, two or three different powers may be procured; to obtain which, some pinion must be shifted, or fresh handle applied or resorted to. In this crane, on the contrary, if the labourer find his load so heavy as to permit him to ascend the wheel without its turning, let him only move a step or two toward the circumference, and he will be fully equal to the task. Again, if the load be so light as scarcely to resist the action of his feet, and thus to oblige him to run through so much space as to tire him beyond necessity, let him move laterally towards the centre, and he will soon feel the place where his strength will suffer the least fatigue by raising the load in question. One man's weight applied to the extremity of the wheel would raise upwards of a ton; and it need not be added, that a single-sheaved block would double that power. Suffice it to say, that the size may be varied in any required ratio; and that this wheel will give as great advantage at any point of its plane as a common walking-wheel of equal diameter; as the inclination can be varied at pleasure, as far as expediency may require. It may be necessary to observe, that what in the figure is the frame, and seems to form a part of the crane, must be considered as a part of the house in which it is

placed; since it would be mostly unnecessary should such cranes be erected in houses already built. With respect to the horizontal part, by walking on which the man who attends the jib occasionally assists in raising the load, it is not an essential part of this invention, where the crane is not immediately contiguous to the jib, although, where it is, it would be certainly very convenient and economical.

Notwithstanding, however, the advantages which have been here enumerated, Mr. Whyte's crane is subject to this theoretical objection, that it derives less use than might be wished from the weight of the man or men; for a great part of that weight (*half* of it, if the inclination be 30 degrees) lies directly upon the plane, and has no tendency to produce motion. Besides, when this crane is of small dimensions, the effective power of the men is very unequal, and the barrel too small for winding a thick rope: when large, the weight of the materials added to that of the men put it out of shape, and give it the appearance of a large, unwieldy, moving floor. We know one large crane of this construction, which has an upright post near the rim on each side, to support it and keep it in shape; and, as much as possible to prevent friction, each post had a vertical wheel at its top. We were informed this crane was seldom used, and that it was soon put out of order. Nor, moreover, is it every situation that will allow the crane rope to form a right angle with the barrel on which it winds, and when this angle is oblique the friction must be much increased. The friction arising from the wheels at top of the vertical crutches might, indeed, be got shut of, by making the inclined wheel very strong; but this would add greatly to the friction of the lower gudgeon of the oblique shaft, and considerably enhance the expense of the machine.

8. There remains, then, another stage of improvement with regard to the structure of cranes, in which the weight of the labourers shall operate, without diminution, at the end of a *horizontal* lever; and in which the impulsive force thus arising may be occasionally augmented by the action of the hands either in pushing or lifting. This step in the progress has been effected by Mr. *David Hardie*, of the East India Company's Bengal warehouse. After a few preliminary observations, we shall point out the distinguishing particulars of this gentleman's invention.

The capstan, the wheel and pinion, with a winch and the walking-wheel, are the cranes in common use at the present time; though a slight view of the method of working these machines might be sufficient to show that they are essentially defective in regard to the grand object in procuring the force

of men, on which the quantity of work performed necessarily depends. The capstan and walking-wheel call for little or no use of the arms; and the crane of the wheel and pinion derives very little advantage from the legs, while the force of the men acting upon the winch must of necessity be very fluctuating. At the capstan, and wheel, and pinion, a considerable force is expended unproductively in giving action to the greater part of the men's weight, which does not contribute to the moving power of the machines; the power actually exerted seldom exceeding 20lbs. at a moderate velocity. The merchants and wharfingers would instantly discharge from their service any porter who would refuse to carry a load of more than 20lbs.; yet these very merchants and warfingers are daily paying full wages to cranemen for exerting a force which, when duly applied, is greatly within the power of a boy of ten or twelve years of age. And as to the common walking-wheel, the men who are stationed within it expend a great portion of their strength in moving themselves *forward;* which proves unproductive, because the effective velocity is only according to the sum of the heights attained, and the waste of force through such unprofitable deviation from the vertical direction renders the men incapable of the due velocity of ascent; besides, the velocity of descent, which ought to be proportional to a due velocity of ascent, is materially impaired by the shortening of the effective lever in the course of its depression, and a consequent diminution of mechanical power; and these obstructions are frequently aggravated, by placing men in the wheel to walk behind the others. And when this loss of labour by the often counter-operation of a rear rank is avoided by applying an additional wheel, the machine occupies much space, becomes extremely expensive, and is attended with extraordinary friction. Although nothing but necessity can justify the hazarding of the lives of men, yet the walking-wheel is attended with imminent danger; and being a very defective engine, employed without either necessity or expediency, those persons who use them are responsible to humanity for the shocking disasters they frequently occasion. But the various evils just enumerated, as well as many others which attend the cranes now adverted to, have been obviated in a very effectual manner by Mr. Hardie; whose crane is at once simple and efficient. It is a walking-crane; but the men walk on the outside of the wheel instead of inside of the rim; and during the whole of their labour they are exposed to no kind of danger, and they can walk in an upright posture, well suited to free respiration. Five cranes of the kind are at work at the East-India warehouses; and as the contrivance (for which Mr. Hardie obtained a patent about

1803) must ultimately prove a considerable acquisition, we have examined the construction and mode of operation of two of these machines with particular attention, that we might be enabled to furnish the public with the following description.

The reader may turn to pl. XI. where fig. 1. is an elevation of the side of the crane on which the men operate.

Fig. 2. An elevation of the end of the stage to assist the men in stepping on and off the wheel, as well as to support a seat for them to rest upon, in the intervals between the operations. The edge *f* of this stage does not stand more than four inches from the point *s* by which the edge of each step passes.

Fig. 3. An elevation of the end of the wheel.

Fig. 4. An elevation of the side of the crane, opposite to that given in fig. 1. The same letters of reference being put to the corresponding parts in these figures.

AA is a wheel (on the principle of the wheel used in China for men working at the chain-pump, for raising water to the higher grounds, employed in the culture of rice), on the outside of which are placed 24 steps for the men to tread upon, at a situation where the steps are found at a height equal to that of the axis, or where the plane of the steps becomes horizontal; the diameter of the wheel being 6 feet, steps included. The crane represented in the figure is adapted for 4 men; though they may easily be contrived for 5, 6, or 8. At one end is B, the crane rope barrel, of a diameter suited to the drafts of goods commonly raised, and the number of men generally allowed, with C a brake wheel, all fixed on the same axis, and D a brake attached to the framing of the crane, to press on the brake-wheel, occasionally to stop or retard the motion; being conducted by a man at the loop-hole by means of E, a lever of wood, loaded with a piece of lead or cast-iron at the extremity, to give it sufficient weight to stop the motion of the wheel; a rope fastened to the end of this lever, and conveyed over two pulleys, terminates in a handle for the loop-hole man, with an iron ring at the lower part thereof to receive a pig, fixed at the side of the loop-hole for the purpose of keeping it down, that the lever might disengage the brake from the brake-wheel during the operation of raising the goods. G, G, G, G, G, are vertical handles, and H, H, H, H, H, horizontal handles for the men to take hold of with both hands, when treading on the steps: sometimes both hands are applied to the vertical handles; at others, one hand to a vertical, and the other to a horizontal handle; and at others, both hands to the horizontal handles; thus producing a variety in the action, and, when necessary, a considerable augmentation to the force. I (fig. 1. and 3.) is a pawl which drops in at every step, to prevent the wheel and its

incumbent weight from overpowering the men at any time: it has at its lower part a cord with a loop to pass over one of the horizontal handles, near the extremity of which there is a notch sufficiently deep to retain the loop when drawn into it, for the purpose of raising the pawl, to disengage it from the wheel preparatory to the operation of lowering the goods or crane-rope.

Now it is obvious, that by treading on the steps as they arrive at the position *t*, *t* (figs. 1. 3.), just above the horizontal plane, passing through the axis, the men both ascend and descend nearly in the vertical directly: of consequence, the greatest possible velocity is produced without any unproductive labour; and the men are enabled to maintain the action by means of a hold of an upright handle on each hand; or occasionally to augment the action, by pushing at these handles. Further, by taking hold of the horizontal handles, each man can, by an act similar to that of lifting, augment the force arising from his weight through all the degrees, from about 150 to 300 lbs. So that the same number of men can perform many operations of raising greater drafts than usual; such as with the common walking-wheel or most other cranes could not be accomplished without additional men: and the pawl which drops in each step provides in the most effectual manner for the safety of the men, even if the crane had not been so constructed that their feet need never be more than 12 inches distant from the stage *sf*, and the distance *fs* far too small to admit of falling through. Thus the very judiciously chosen dimension of a 6-feet diameter unites the advantages of a weight acting on a horizontal instead of inclined lever with those accruing from the vertical and horizontal handles; while it completely precludes the danger which attends the common walking-wheel, and has by no means so much friction as necessarily attends Mr. Whyte's crane.

Mr. Hardie has likewise contrived a truly advantageous mode of operating without a gibbet, which he has carried into effect with four of his cranes. He has placed the crane at the top of the warehouse, so as to allow the crane-rope to drop directly down from the barrel of the crane in front of the loop-holes; and at the upper floors, where the shortness of the rope diminishes the swing of the goods in or out of the loop-holes, he has provided a sliding floor immediately under the floor of the warehouse, which one man draws out or in, by pulling a cord, with the greatest ease, to receive or deliver the goods by a truck at the loop-hole. The part of the warehouse floor which is immediately above the sliding floor consists of a thin plate of cast iron, which allows the truck to run off the one on the other

without any obstruction. Thus more than one man's labour in five or six is saved, by getting rid of the friction of the pulley of a gibbet: and a still greater saving of labour is effected by accelerating all the movements at the loop-holes.

9. The common method of lowering goods by the brake and brake-wheel, even with the assistance of a counter-weight, is liable to injurious accidents to the men, as well as to the goods, when they consist of perishable articles, such as wine, spirits, glass, &c. Sometimes, from the rapid motion of the crane, parts of it fly off with violence, and kill or wound the persons near it: at other times the brake-rope becomes entangled by turning off the pulleys or otherwise, or the rope slips out of the hand of the man who conducts it: in either of which cases the goods might descend with all the accelerated velocity of a falling body, receiving damage, and killing or maiming the men, horses, &c. which happen to be under them. But these evils are completely remedied by a *lowering regulator* of the following description, invented by Mr. Hardie.

Pl. XI. fig. 5. A section of the regulator.

Fig. 6. An elevation of one end of the regulator. The same letters of reference being put to the corresponding parts in these figures.

AA, a cast-iron box fixed to the floor B, divided into two compartments, each 10 inches long, one of 4 inches diameter, and the other of 2 inches diameter: these are both filled with oil, a liquid not subject to any material change by frost; or they may be filled with water in summer and mild weather; and some spirituous liquor (gin, for instance) in frosty weather. The two cylinders communicate with each other by C, an aperture at their top, and D, an aperture at their bottom; the smaller compartment having a cock E, with its axle passing through the side of the iron box, guarded by a stuffing-box, and G a quadrant with notches fixed at its end, to receive H the iron claw, which keeps the cock in its proper situation, and shows the extent of its apertures when opened. The larger compartment has a piston F, with its rod passing through I, the top of the iron box (guarded here also by a stuffing-box), and passing through a guide: this rod is connected with a joint moved by a crank, which is turned by a pinion P of about six teeth; and this pinion is moved by a wheel, of a size suited to the diameter of the barrel of the crane and the weight of the goods commonly lowered: this latter wheel is fixed to the axle of the crane by a simple mode of connexion, which admits of its being disengaged during the operation of rising; it is also provided with the barrel rope and counter-weight, which are commonly used for the

purpose of winding up the slack crane rope on the barrel of the crane, to be ready to repeat the operation of lowering.

If the cock E were quite shut, the oil or other liquid confined between it and the piston would prevent the piston from moving, and of course hinder the goods hanging from the wheel, &c. connected with P, from descending; but if the cock were opened a very little, the oil would pass slowly through it, and would therefore allow the piston F to move up and down slowly, and the goods to descend slowly also; and, in like manner, a further opening of the cock will permit the load to descend with a greater velocity: thus the cock, by being more or less opened, gives the precise velocity desired to the descent of the goods, whatever their weight may be.

When a small pinion turned by a winch is applied to the tooth-wheel, occasionally employed to turn the pinion of the crank, one man with ease raises the goods an inch or two, in order to be swung from the floor preparatory to lowering; the natural defect of the winch as a raising instrument being of no consideration in such case, where the goods are raised merely to clear the floor: so that this crane and lowering apparatus possesses a much higher degree of perfection in lowering than any of the other cranes. The means afforded of regulating it to lower either small or great weights with facility, expedition, and safety, and without depending, during the operation, on the precarious attention and management of a man, render it, in our opinion, far preferable to the hazardous and limited mode of lowering goods by the brake; while, with respect both to safety and great saving of labour, it obviously surpasses the modes of lowering by the capstan and the walking wheel, which require nearly the same number of men to lower that they take to raise any weight.

We have dwelt the longer upon the subject of cranes, because it is manifestly of the first importance in a commercial nation: something further, of too much utility to be entirely omitted, may perhaps be found under the articles ENGINE *to let down weights*, GIBBET, HARRIOT'S *Engine*, and LOADING *and unloading of goods*.

CRANE is also a popular name for a syphon employed in drawing off liquors.

This crane or syphon is nothing else than a bent tube, as ABG (fig. 5. pl. X.) If the shorter end AB be immersed in a vessel of water or other fluid C, then by applying the mouth to the end G, and sucking till the liquor arrives there, it will continue to flow out at the end G, as long as that end is lower than the surface of the fluid in the vessel C. If there be a mouth-

piece at E, then sucking at that mouth-piece (while the end G is stopt with a finger or otherwise) will make the fluid flow when the obstruction is taken away from G. When the fluid has begun to flow, the hole at E must be stopped up, or the fluid will flow no longer than till the surface in the vessel be as low as E.

The reason of the motion of the liquor in the syphon is this: the perpendicular height of the column BG being greater than that of BA, the pressure at G is greater than at A; and the pressure of the atmosphere being the same at both orifices (supposing them of equal area), therefore the weight at G will cause the fluid to flow out there, while the pressure of the atmosphere will force more liquor up the end A; and thus the motion will continue so long as there is any fluid in the vessel, provided the end G is lower than the end A of the syphon. Hence it is manifest, that the height from the surface of the fluid in the vessel to the top B of the syphon must not exceed the altitude of a column of the fluid whose weight is equal to the pressure of the atmosphere on the same base.

The operation of sucking out the liquor at G, which is often both disagreeable and troublesome, may be prevented by having an aperture at the top B, through which the syphon may be completely filled, and then that aperture closed again. Or a small syphon may be inverted, and filled with the fluid, which may be kept in by a finger applied at each end until it is placed in the proper position for work, when the fingers may be removed.

The syphon will raise a stream of water through an extensive space in every situation where a little descent can be procured; but while the operation continues, no water can be taken directly out of the stream above the lowest part of the tube. When, however, the two open ends of a syphon are closed, a quantity of water may be let out of the highest part, and its place supplied by introducing a like quantity which is of no other use: all the avenues for the purpose being then closed, and the stream suffered to flow through the tube, the useless water will be displaced, and a fresh quantity may be soon after drawn off. This mode of exchange may be useful in furnishing a supply for washing, and some other purposes; but there are several domestic uses for which the water drawn off will not be thought sufficiently pure. A method of taking water out of the syphon at any height within the limits of the elevation, without retarding the stream or introducing another quantity, has long been thought very desirable. Mr. *William Close*, of Dalton, made a number of experiments and observations to determine

the practicability of the project; from which he at length deduced the following arrangement for extracting a quantity of *water* out of a syphon at any elevation (within its limits), and supplying its place with *air*.

Into any part except the top side of a vertical syphon SY (fig. 5. pl. X.) insert two small pipes, and let their apertures in the inside of the tube be divided by a projecting piece about a quarter of an inch thick; wherever the pipes are inserted, the piece must be placed in such a position that the current will strike against one of its flat sides. The pipe which opens on that side of the obstacle or dam struck by the stream may be called the *water-pipe*, and that on the other side the *air-pipe*. Insert their other ends into a vessel *aw*. The air-pipe opposite to *a* must rise to near the top of this vessel, but the water-pipe *w* need not arise above the place of its insertion. A cock, perfectly air-tight, must be fixed in each pipe between the vessel and syphon: the vessel *aw* must have a tube *t* in its lower part, for letting out water; and this tube must have a cock fixed in it, or a valve covered with leather to close its lower end. To hasten the delivery of the water in this vessel, the external air may be admitted, in such manner as is most convenient.

The communication between the vessel and syphon being intercepted by turning the cocks in the pipes *aw*, and the branches of the syphon closed at their lower ends, the tube may be filled with water through an aperture in the top. After this aperture is closed, and a stream of water let into the cistern C for supplying the syphon, the ends of the branches may be opened, and a continued stream will flow through the tube.

When it is required to fill the vessel *aw* with water, exclude the external air, and open the pipes between it and the syphon. The vessel will soon be filled, and the water may be let out by opening the tube *t*, after the small pipes *aw* are again closed by turning their cocks.

The water may be let out of the vessel without attendance, by a quantity of water passing through four vessels placed in the following order one below another, and each provided with a syphon.

1. The highest, an immoveable vessel filled in a given time. 2. A descending vessel, suspended from a lever or a wheel, which turns the cocks in the tubes opposite *aw* in its axis. This vessel must have a tube open at both ends, fixed in the middle of its bottom. 3. A descending vessel, to open the valve for letting water out of the vessel *aw*. It must be suspended upon the valve by a cord or wire passing through the tube, in the middle of the second vessel. 4. The lowest, a ves-

sel of the same width with the second. The brim of it must be connected to the outside circumference of the bottom of the second, by wires or chains.

In this arrangement the first vessel will empty itself into the second, which will close the cocks in the pipes opposite *a* and *w*, before air is admitted into the vessel *aw*. The third will be filled from the second, and the water in the vessel *aw* will be let out again; the third will deliver its contents into the fourth or lowest, which will keep the cocks in the small pipes opposite *a* and *w* close, until after the third vessel is empty, has risen up, and the external air can no longer enter the vessel *aw*. The fourth being then emptied by its syphon, the pipes between the vessel *aw* and syphon SY will open.

The diameter of the second vessel should be something less than either that above or below it. The fourth should be filled before the second is empty: the third will descend last, and rise first: the second and fourth will rise together, immediately after the third. If the second and fourth were to rise before the third, the syphon would directly receive a quantity of external air, and its operations would cease. It will, therefore, require much caution to manage the cocks and valves, if another vessel similar to *aw* is to be filled while this last is emptied, and emptied while it is filled.

The vessel *aw* should not be large; and, in order to overcome the buoyance of the extracted air, it is advisable to make the length of the descending branch of the syphon exceed the length of the ascending one as much as circumstances will admit, and to let the lowest part of it be made of a conical divergent form. The velocity of the stream will be thus increased; the vessel *aw* will be sooner filled with water; and the depression of the two columns will be less liable to happen from very slight imperfections of workmanship. (*Nicholson's Journal*, 4to. vol. IV. p. 550.)

Mr. Close made many subsequent trials, to bring this apparatus to the greatest perfection it would admit of: the result of the whole may be seen in No. 45. of the New Series of Nicholson's Journal, where Mr. Close has given the description and effects of an apparatus for raising water by means of air condensed in its descent through an inverted syphon.

Nearly analogous to this contrivance by Mr. Close, is the syphon machine of Mr. Detrouville, described by M. Hachette in his Traité Elémentaire des Machines.

M. Venturi, also, of whom mention is made in the 1st vol. of this work, has so blended his discovery of the *lateral* communication of motion in fluids, with the principle of the syphon, as to raise water out of a lower reservoir, and pass off with the

water spouting from a higher one. Imagine that not more than 30 feet below the horizontal pipe, whose orifice is CD (fig. 5. pl. XVII. vol. I.) there is a reservoir from which we wish to raise water by means of a syphon. Let the longer branch of that syphon rise vertically from the surface of the water below, till it is a few inches above the horizontal pipe PBD, and then turn so that the descending branch shall just enter the top of that horizontal pipe; the place of insertion being rendered air-tight. Then, while water in the vessel MNOP escapes through the horizontal pipe, it will, by virtue of the lateral communication of motion in fluids, carry on with it a portion of air from the syphon. Thus, rarefying the air left behind, the water in the lower reservoir will, by means of the atmospheric pressure, be thrust up the rising branch of the syphon. This operation continuing, in a very short time the air will all be expelled from the syphon, and the same lateral communication of motion will be the means of drawing water from the lower reservoir so long as it continues to flow from the upper one.

CYLINDERS *for* STEAM ENGINES, *boring of*, is an operation usually carried on at the foundery where they are cast. Though the moulder pursues the most correct method his art is capable of, yet it is impossible to be certain, that when the mould has received the metal from the furnace, it shall come out quite straight; and if it should come out crooked, it must remain so; for the old method of boring will never make it otherwise in that respect. It is not like boring a piece of metal which is quite solid, as in boring guns, &c. All the old boring can do to a cylinder is to make it round and smooth, for there is nothing to conduct the boring bit in its progress through the piece but the form given it by the moulder; and a piece bored after this manner may look very well, yet if it is not straight it is not a cylinder: and an engine executed with such a vessel as that will be good or ill in that respect, as it approaches to or is further off the degree of exactness constituting it a cylinder.

The new method of boring (which, as is observed, article STEAM ENGINE, was first practised at Burham, a foundery belonging to Mr. Wilkinson, iron-master) insures all the perfection the subject is capable of; and when the process is conducted by an intelligent workman, if the cylinder should be cast ever so crooked, or ever so thick on one side more than another, he can take out the redundancy on that side, and but scarcely touch the other. This will be easily admitted when it is understood that, whereas in the old method of boring, the instrument which performs the part of cutting the metal is guided in its progress by the already incorrect form of the piece itself; but in the new method, the cutting apparatus is conducted

along a thing which in itself is a masterpiece of workmanship, a perfect cylinder, and is what the workmen call *the boring bar*, and is cast of the best pigs that can be procured, and turned with the utmost care and precision: consequently, whatever is conducted along this bar will proceed in a right line; and as it is intended that this shall be the conductor of the cutter-block, being furnished with proper cutters, it must cut the interior surface of the piece quite straight, though it may have been ever so crooked berore.

Then this bar being turned very true, it is to have a groove or two cut opposite to each other, in a line parallel to its axis; then there is a socket of cast iron, of such dimensions as to suit for cylinders of various diameters, and this socket is to be nicely bored and ground on the bar; and then it must have a fillet or two (according to the groove or grooves in the bar) let in on the inside, so as to slide along the bar, but not to turn round upon it: the external part must be made conical, with four or six studs upon the base of it to receive the cutter-block. The next thing is to give a progressive motion to this socket and cutter-block while the bar is turning on its own axis; and that is done by some with a collar of metal fitted on the socket, and to that collar are connected two racks, long enough to reach through the cylinder and communicate with a pair of pinions, by which the socket is drawn or pushed along the boring bar by the means of two levers, carrying a weight at each sufficiently heavy to overcome all resistance in the operation.

Another method of giving a progressive motion to the block is to drill a hole through the whole length of the bar, to admit a single rod, to be communicated to the socket by sinking *the groove* (for in this case there can be but one) entirely through one side of the bar, so as to come into the hole that has just been drilled through the bar. Then a branch from the internal part of the socket must be fitted into the groove with an eye to receive the end of the rod, which is then to be furnished with a key, or a nut and washer, to keep it in its place while the bar and socket is turning round, and a weight with a rope over a pulley is applied to give motion to the socket, along the bar. This is the best way of applying this method to boring of small cylinders, because there is no incumbrance upon the socket; and if the bar is sufficiently strong, it will move with great steadiness.

ELLIPSOGRAPH is the name given by the anonymous author of a German publication, entitled "*Beschreibung eines Ellipsograph, womit man wahre Ellipsen ohne Berechnung der Brennpunkte sehr leicht beschreiben kann*," &c. published at Gotha in 1794, to a simple and universal instrument for drawing ellipses. The instrument has been long known to our ma-

thematicians, and has been described, though not in such general terms as it admits of, in Emerson's Conics, Hutton's Mathematical Dictionary, and other works; but as it has not yet been adopted for practical purposes, though it is far preferable, in our opinion, to any instrument for drawing ellipses now in use, we take this opportunity of recommending it to general notice.

The ellipsograph consists of three flat and moderately thin rulers of wood or brass, two of which must be of equal lengths; and it may be as well if the length of these two together be equal to that of the third ruler. Let the two shorter of these rulers be pierced with a number of holes at equal distances, the holes being capable of receiving either a pin on which the rulers may turn as upon a joint, or a pencil by which the curve may be described: then, by connecting these rulers, either as in fig. 5. or fig. 6. pl. XIV. an ellipse may be readily described. Thus, in fig. 5. hang one end of the ruler AB upon a pin in the middle of the ruler KL, and take the point B such that AB = BD, and AB + BD = semiconjugate + semitransverse of the ellipse, the ruler BD turning upon a pin in B as a joint: take the point E so that DE = semiconjugate, and put a pencil into the hole of that point: then, if the end D of the ruler BD be slidden along the edge KL of the ruler which passes through the centre A, the pencil at E will describe a true ellipse having the proposed diameters. Again, taking the method represented in fig. 6. upon the ruler AC, hang the ruler BG at B, so that AB + BE = semitransverse, while AB = BD = half the difference of the semitransverse and semiconjugate axes: then, while a pin at D slides along the edge of the ruler KL, the pencil at E will describe the ellipse required. The truth of this method of construction is demonstrated in Emerson's Conics, prop. 75. ellipse.

This instrument may, it is obvious, be easily made either so as to construct small ellipses, now commonly described by means of the elliptical compasses; or upon a larger scale, for the purpose of describing elliptical centring for arches of bridges, &c. In the latter case the ellipsograph may be made sufficiently strong without being any way cumbersome in practice. In the actual construction of the instrument the ruler KL should be the thickest, and the other two legs made to run upon friction rollers, as in the construction of the pentagraph.

It may not be altogether useless just to remark, that in both methods of using the instrument, the point B will describe a circular arc; and if the ruler DB had a part *above* B, equal to DB, the upper extremity of that part would, during the motion of the point D along KL, describe a right line. This follows evidently from what was shown in art. 8. of the introductory part of this volume.

ENGINE *to let down heavy weights.* The simple method we are now about to describe was invented by father *Ressin*, in 1714. Suppose it were required to lower large stones from the top of a wall which is intended to be taken down: erect a frame, or set up a gin close by the side of the wall, and let the pulley P (fig. 4. pl. IV.) be firmly attached to this frame. Over this pulley must pass a cord, one end of which C has a hook to which the stone, &c. can readily be fastened; the other end D carries a vessel, which may be filled with water from the reservoir M, on the ground at the bottom of the wall. Then, while one man is fixing the stone to the hook at the top of the wall, let another put water into the vessel D at the bottom till it nearly equals the weight of the stone: after which, leaving both to the free operation of gravity, or checking the motion a little if necessary, the stone will gradually descend to the ground, while the vessel D will be carried up to a funnel A, into which the water may be poured, and thence conveyed by a wooden or a leather pipe to the reservoir M. Then the vessel D may be suffered to descend, and the hook C will be raised to be fixed to another stone: and thus the operation may be repeated as often as is necessary.

The same method may likewise be adopted in lowering sacks from a high granary, or packages from an upper warehouse. The velocity of the descending weight may be so regulated as to have any proportion to that which gravity imparts to bodies falling freely: thus, if W denote the weight to be lowered, V that of the vessel of water, we shall have $\frac{W-V}{W+V}$, for the fraction expressing the ratio of the velocity to that freely imparted by gravity when denoted by unity. Thus, if $V=\frac{1}{2}W$, the weight will fall through $\frac{1}{3}$ of $16\frac{1}{12}$, or about $5\frac{1}{3}$ feet in the first second: if $V=\frac{2}{3}W$, the weight will fall through $\frac{1}{5}$ of $16\frac{1}{12}$, or about $3\frac{1}{5}$ feet in the first second: the friction of the pulley being in both instances disregarded *.

EPROUVETTE, *powder-prover*, is an instrument contrived for the purpose of comparing the strength of different kinds of gunpowder. One of the best for the proof of powder in artillery, is that contrived by Dr. Hutton. It consists of a small brass gun, about $2\frac{1}{2}$ feet long, suspended by a metallic stem or rod, turning by an axis on a firm and strong frame, by means of which the piece oscillates in a circular arch. A little below the axis, the stem divides into two branches, reaching down to the gun, to which the lower ends of the branches are

* *Engines* were first called *engenios* or *ingenios*, from *ingeniosus*, adapted, or *ingenium*, a device or contrivance. The following is a copy from a London Newspaper, dated January 6th, 1679: " At Mr. Topies in the Little Minories, there is to be sold two frames or *engenios* to make silk stockings."

fixed, the one near the muzzle, the other near the breech of the piece. The upper end of the stem is firmly attached to the axis, which turns very freely by its extremities in the sockets of the supporting frame; by which means the gun and stem vibrate together in a vertical plane, with a very small degree of friction. The piece is charged with a small quantity of powder (usually about two ounces) without any ball, and then fired; by the force of the explosion, the piece is made to recoil or vibrate, describing an arch or angle, which will be greater or less, according to the quantity or strength of the powder.

To measure the quantity of recoil, and consequently the strength of the powder, a circular brazen or silvered arch of a convenient extent, and of a radius equal to its distance below the axis, is fixed against the descending two branches of the stem, and graduated into divisions, according to the purpose required to be answered by the machine: viz. 1. Into equal parts, or *degrees*, for the purpose of determining the angle actually described in the vibration. 2. Into unequal parts, according to the *chords*, being in fact 100 times the double sines of the half angles, and running up to 100, as equivalent to 90 degrees; these serve to compare the *velocities* given by the powder. 3. Into unequal parts according to the versed sines; they are, in truth, 100 times the versed sines of our common tables, $141\frac{1}{2}$ corresponding with 90 degrees; these serve to compare the *forces*.

The divisions in these scales are pointed out by an index which is carried on the arch during the oscillation, and then, stopping there, shows the actual extent of the vibration. Two ounces of powder give, on an average, as I have found by several trials, about 36 on the chords, or about 21° on the arch. For a more minute description with diagrams, see Hutton's Tracts, vol. iii. p. 153.

The late Mr. Ramsden constructed an eprouvette, which differs from the preceding simply by the gun's recoiling in a direction parallel to itself instead of its vibrating as a pendulum. In order to this, the gun is suspended upon two hanging frames, one at each end, like ladders. They are equal in length, and serve like the joints of a parallel ruler, to make the gun rise and fall, during its recoil and return, so as always to retain a direction parallel to itself; that is, the horizontal direction. The degrees are measured upon a fixed arch, by means of a moveable index, nearly as in Dr. Hutton's eprouvette.

For other eprouvettes by Regnier, &c. the reader may consult the article Powder Provers in the *Pantologia*. Those of D'Antoni may be seen in Captain Thomson's Translation of his Gunnery.

FILES, *machines for cutting of.* There have been various contrivances for this purpose; but one of the best we are acquainted with is described in the Transactions of the American Philosophical Society, and is as follows: AAAA fig. 6. pl. X. is a bench made of well-seasoned oak, the face of which is planed very smooth. BBBBB the feet of the bench, which should be substantial. CCCC the carriage on which the files are laid, which moves along the face of the bench AAAA parallel to itss ides, and carries the files gradually under the edge of the cutter or chisel HH, while the teeth are cut: this carriage is made to move by a contrivance somewhat similar to that which carries the log against the saw of a saw-mill, as will be more particularly described. DDD are three iron rods, inserted into the ends of the carriage CCCC, and passing through holes in the studs EEE, which are screwed firmly against the ends of the bench AAAA, for directing the course of the carriage CCCC, parallel to the sides of the said bench. FF two upright pillars, mortised firmly into the bench AAAA nearly equidistant from each end of it, near the edge, and directly opposite to each other. G the lever or arm which carries the cutter HH (fixed by the screw I), and works on the centres of two screws KK, which are fixed into the two pillars FF in a direction right across the bench AAAA. By tightening or loosening these screws the arm which carries the chisel may be made to work more or less steadily. L is the regulating screw, by means of which the files may be made coarser or finer; this screw works in a stud M which is screwed firmly upon the top of the stud F: the lower end of the screw L bears against the upper part of the arm G, and limits the height to which it can rise. N is a steel spring, one end of which is screwed to the other pillar F, and the other end presses against the pillar O, which is fixed upon the arm G; by its pressure it forces the said arm upwards, until it meets with the regulating screw L. P is an arm with a claw at one end marked 6, the other end is fixed by a joint into the end of the stud or pillar O; and, by the motion of the arm G, is made to move the ratch-wheel Q. This ratch-wheel is fixed upon an axis, which carries a small trundle-head or pinion R, on the opposite end; this takes into a piece SS, which is indented with teeth, and screwed firmly against one side of the carriage CCCC: by means of this piece motion is communicated to the carriage. T is a clamp for fastening one end of the file ZZ in the place or bed on which it is to be cut. V is another clamp or dog, at the opposite end, which works by a joint W, firmly fixed into the carriage CCCC. Y is a bridge, likewise screwed into the carriage, through which the screw X passes, and presses with its lower end against the upper side of

the clamp V; under which clamp the other end of the file ZZ is placed, and held firmly in its situation while it is cutting, by the pressure of the said clamp V. 7777 is a bed of lead, which is let into a cavity formed in the body of the carriage, something broader and longer than the largest fixed files; the upper face of this bed of lead is formed variously, so as to fit the different kind of files which may be required. At the figures 22 are two catches which take into the teeth of the ratch-wheel Q, to prevent a recoil of its motion. 33 is a bridge to support one end 4 of the axis of the ratch-wheel Q. 5 a stud to support the other end of the axis of that wheel.

When the file or files are laid in their place, the machine must be regulated to cut them of the due degree of fineness, by means of the regulating screw L; which, by screwing further through the arm M, will make the files finer, and, *vice versa*, by unscrewing it a little, will make them coarser; for the arm G will, by that means, have liberty to rise the higher, which will occasion the arm P, with the claw, to move further along the periphery of the ratch-wheel, and consequently communicate a more extensive motion to the carriage CCCC, and make the files coarser.

When the machine is thus adjusted, a blind man may cut a file with more exactness than can be done in the usual method with the keenest sight: for by striking with a hammer on the head of the cutter or chisel HH, all the movements are set at work; and, by repeating the stroke with the hammer, the files on one side will at length be cut: then they must be turned, and the operation repeated, for cutting the other side. It is needless to enlarge much on the utility or extent of this machine; for, on an examination, it will appear to persons of but indifferent mechanical skill, that it may be made to work by water as readily as by hand, to cut coarse or fine, large or small, files, or any number at a time; but it may be more particularly useful for cutting very fine small files for watchmakers: as they may be executed by this machine with the greatest equality and nicety imaginable. As to the materials and dimensions of the several parts of this machine, they are left to the judgment and skill of the artist who may have occasion to make one; only observing that the whole should be capable of bearing a good deal of violence.

FIRE-ESCAPE, a machine for removing persons from the upper stories of houses on fire. It consists of a pole, a rope, and a basket. The pole is of fir, or a common scaffold pole, of any convenient length from 36 to 46 feet. The diameter at bottom, or greatest end, about five inches: and at the top, or smallest end, about three inches. At three feet from the top is

a mortise through the pole, and a pulley fixed to it of nearly the same diameter with the pole in that part. The rope is about three quarters of an inch diameter, and twice the length of the pole, with a spring hook at one end, to pass through the ring in the handle of the basket when used: it is put through the mortise over the pulley, and then drawn tight on each side to near the bottom of the pole, and made fast there till wanted. The basket should be of strong wicker-work, three feet and a half long, two feet and a half wide, rounded off at the corners, and four feet deep, rounding every way at the bottom. To the top of the basket is fixed a strong iron curve or handle, with an eye or ring in the middle; and to one side of the basket, near the top, is fixed a small cord, or guide-rope, of about the length of the pole. When the pole is raised, and set against a house over the window from which any persons are to escape, the manner of using it is so plain and obvious, that it need not be described. The most convenient distance from the house for the foot of the pole to stand, where practicable, is about 12 or 14 feet. If two strong iron straps, about three feet long, riveted to a bar cross, and spreading about 14 inches at the foot, were fixed at the bottom of the pole, this would prevent its turning round or slipping on the pavement; and if a strong iron hoop, or ferule, riveted (or welded) to a semicircular piece of iron spreading about twelve inches, and pointed at the ends, were fixed on at the top of the pole, it would prevent its sliding against the wall.

When these two last-mentioned irons are fixed on, they give the pole all the steadiness of a ladder; and because it is not easy, except to persons who have been used to it, to raise and set upright a pole of 40 feet or more in length, it will be convenient to have two small poles or spars of about two inches diameter, fixed to the sides of a great pole at about two or three feet above the middle of it, by iron eyes riveted to two plates, so as to turn every way; the lower end of these spars to reach within a foot of the bottom of the great pole, and to have ferules and short spikes to prevent sliding on the pavement, when used occasionally to support the great pole like a tripod. There should be two strong ash trundles let through the pole, one at four feet and one at five feet from the bottom, to stand out about eight inches on each side, and to serve as handles, or to twist the rope round in lowering a very heavy weight. If a block and pulley were fixed at about the middle of the rope, above the other pulley, and the other part of the rope made to run double, it would diminish any weight in the basket nearly one-half, and be very useful in drawing any person up to the assistance of those in the chambers, or for removing any effects

out of a chamber, which it might be dangerous to attempt by the stairs.

It has been proved, by repeated trials, that such a pole as we have been speaking of can be raised from the ground, and two or three persons taken out of the upper windows of a house, and set down safely in the street, in the space of 35 seconds, or a little more than half a minute. Sick and infirm persons, women, children, and many others, who cannot make use of a ladder, may be safely and easily brought down from any of the windows of the house on fire by this machine, and by putting a short pole through the handles of the basket, may be removed to any distance without being taken out of the basket. The pole must always have the rope ready fixed to it, and may be conveniently laid up upon two or three iron hooks under any shade or gateway, and the basket should be kept at the watch-house. When the pole is laid up, the two spars should always be turned towards the head of it. The basket should be made of peeled rods, and the pole and spars painted of a light stone-colour, to render it more visible when used in the night.

Other ingenious contrivances for this purpose are described in Mr. Bosworth's "Accidents of Human Life;" and for Mr. Ballantyne's Fire Engine and Fire Escape, see No. 42 of the *Glasgow Mechanics' Magazine*, sold by Steuart, Cheapside.

FIRE-ENGINE, the name now commonly given to a machine by which water is thrown upon fires in order to extinguish them. Various machines have been contrived for that purpose at different times; the most essential particulars in a few of which we shall here describe.

The usual construction of the fire-engine, after the great improvements were made in it by Mr. R. Newsham, was nearly that which is exhibited in fig. 2. pl. XV. where we have represented a vertical section of the engine. The motion of the water in this machine is effected by the pressure of the atmosphere, the force of men acting upon the extremities H′, H″, of a lever, and thence giving motion to the pistons, and by the elasticity of condensed air, in the following manner:—When the piston R is raised, a vacuum would be made in the barrel TU if the water did not follow it from the inferior canal EM (through the valve H), which rises through the tube EF immersed in the water of a vessel by the pressure of the atmosphere on its surface. The water of the barrel TU, by the succeeding depression of the piston R, shuts the valve H, and is forced, through the superior canal ON, to enter by the valve I into the air-vessel *abcd*; and the like being done alternately with respect to the other barrel WX, and its piston S, the air-vessel is, by these means, continually filling with water, which greatly compresses

the air above the surface of the water in that vessel, and thereby proportionally augments its spring: which at length is so far increased as to re-act with great force on the surface YZ of the subjacent water, and compel it to ascend through the small tube *ef* to the stop-cock *eg*, where upon turning the cock the water is suffered to pass through a pipe *h* fixed to a ball and socket; from the orifice of which it issues in a continued stream with a great velocity, to a considerable height or distance; and it is usually kept from diverging too soon in its progress by means of a long series of flexible leather pipes, properly joined together, and known among the fire-men by the name of the hose.

Desaguliers remarks (vol. I. p. 257.) that Mr. Newsham contrived his engines in such a manner, "that part of the men who work them exert their force by treading, which is more effectual than any other way that men can work at such engines; the whole weight of the body being sufficiently thrown on the forces of the pumps: and even part of a man's strength may be added to the weight by means of horizontal pieces to which he can apply his hands when he is treading; whereas, by applying the hands to move levers or turn winches, the power must act very unequally. This is the reason why with the same number of men he has generally thrown water further, higher, and in greater quantities, with the same sized engines, than other engineers who have tried their engines against his." Notwithstanding the truth of this remark, we are not aware that the combination of human weight and strength here recommended has been practised in any subsequent fire-engines, or indeed in any machines whatever, except the ingenious walking crane of Mr. Hardie.

The greatest artifice in the engine according to the construction just described is the contrivance to produce a *continual stream*, which is done by the compression and proportional elasticity of air in the barrel *abcd*, called the air-vessel. For the air, being an elastic fluid, will be susceptible of compression in any degree by the water forced in through the valves at IK; and, since the force of the air's spring will always be inversely as the space it possesses (art. 489. vol. I.), it follows that when the air-vessel is half full of water the air will be compressed into half the space it possessed at first, and therefore its spring will be twice as great as at first.

But this spring at first was equal to the pressure of the atmosphere on the same surface: for if it were not it could not have sustained or resisted the pressure of the atmosphere which stood over it, and consequently could not have filled the vessel before the water was driven in; which yet we find it did, and maintained an equilibrium with the common air. The vessel

then being half filled with water, or the air compressed into half the first space, its spring will in this case be equal to twice the pressure of the atmosphere; and therefore when the stop-cock at *p* is turned, the air within, pressing on the subjacent water with twice the force it meets with from the external air in the pipe *ef*, will cause the water to spout out of the engine to the height of 32 or 33 feet, if the friction is not too great.

When the air-vessel is $\frac{2}{3}$ full of water, the air takes up $\frac{1}{3}$ part; whence its spring will be three times as great as that of the common air, and it will project the water with twice the common atmospheric pressure; consequently, it will rise to the height of 62 or 64 feet. When the air-vessel is $\frac{3}{4}$ full of water the air will be compressed into its $\frac{1}{4}$ part, and so will protrude the water with three times the atmospheric pressure, and carry it to the height of 96 or 99 feet. Hence it will be easy to state the law by which the spring of the air will act on the surface of the water below it, as in the following table.

Height of water in air-bar.	*Of the air compressed.*	*Proportion of air's elasticity.*	*Height of the spout.*
$\frac{1}{2}$	$\frac{1}{2}$	2	33
$\frac{2}{3}$	$\frac{1}{3}$	3	66
$\frac{3}{4}$	$\frac{1}{4}$	4	99
$\frac{4}{5}$	$\frac{1}{5}$	5	132
$\frac{5}{6}$	$\frac{1}{6}$	6	165
$\frac{6}{7}$	$\frac{1}{7}$	7	198
$\frac{7}{8}$	$\frac{1}{8}$	8	231
$\frac{n-1}{n}$	$\frac{1}{n}$	n	$(n-1)\ 33$

Various alterations and improvements have been made from time to time in the construction of Fire-engines. The contrivers of some of these improvements, as Messrs. Bramah, Dickenson, Simpkin, Rowntree, and Phillips, have secured their inventions from infringement by patents; the specifications of most of which may be seen in the Repertory of Arts and Manufactures. In the year 1785 the silver medal and twenty guineas were conferred by the "Society for the Encouragement of Arts," &c. on Mr. Furst, as a reward for his contrivance to increase the effect of engines in extinguishing fires; of which the following is a short description: from a platform rises an upright pole or mast, of such height as may be judged necessary; a gaft slides upon it in an ascending direction, and along both is conveyed the leather hose from the engine. The branch or nose-pipe of the engine projects at the extremity of the gaft; towards which an iron frame is fixed, whence two chains are suspended; and

from these hang ropes, which serve to give an horizontal direction to the branch; while other ropes, that run through proper pulleys, and are thus conveyed down the mast, serve likewise to communicate a vertical motion to it. By these means, the branch or nose-pipe of the engine is conducted into the window of any room where the fire more immediately rages; and the effect of the water discharged is applied in the most efficacious manner to the extinguishing of the flames.

A very cheap and simple fire-engine is that invented in America by Mr. *Benjamin Dearborn*, who communicated it to the American Academy of Arts and Sciences, from whose Memoirs for 1794 we extract the following particulars:

Fig. 4. pl. XV. AB and CD are the edges of two planks, confined by four bolts; *a b* and *c d* are two cylindrical barrels, in each of which a piston, with a valve, is fastened to the spear *e*, and is moved up and down alternately by the motion of the arms EE. Beneath each barrel a hole is made through the plank AB, which is covered with a valve. The arms EE are suspended on the common centre *f*: there are also arms parallel to these on the opposite side: *gg* are the ends of handles which are fastened across the ends of the arms. At *h* a bolt goes across from arm to arm, to which the piece *ik* is affixed, and on which it plays; the lower end of this piece is fastened to the top of the spear *e*. G*lf* is a standard for the purpose of supporting the arms, to which there is a correspondent one on the opposite side; both are notched into the edges of the planks, where they are secured by a bolt, which passes through them at *l*, and has a nut or fore-lock on the opposite side. HI, HI, are square braces, answering the purpose of ducts, through which the water ascends from the barrels, passing through the plank at *m*. KL, KL, are irons in the form of a staple, in order to confine the braces: the lower ends of these irons meet, and are secured by a bolt passing through them, and MN*no*, which is a piece that goes up through a mortise in the centre of the planks. This piece is square from the lower end, till it reaches the top of the braces; whence they become cylindrical to the top, the upper end being perforated sufficiently low down, in order to communicate with the braces. OP is an iron ring that surrounds the tube, and has two shanks which ascend through the head, which screws on the top at *pq*; *rs* is a ferule nailed round the tube.

Fig. 5. is the same engine; the arms and standards being taken off, in order to delineate more clearly the mode of securing the braces; an object which is completely effected by a wedge driven into the mortise *a*: beneath the upper plank *b* is a hole for admitting a passage to the bolt, which secures the

standards. In this figure a side view of the head is given, with the pipe in a perpendicular direction.

The machine is confined within a box, set on wheels, as in the common fire-engines. The whole is made of wood, excepting the spears of the pumps, and a few bolts, &c. The advantages of this machine are, that it can be made in any place where common pumps are manufactured; that the interior work will not exceed one-fourth of the price of those which are constructed on the usual plan; and that they are incomparably more easy to work than the common ones: circumstances which strongly recommend the American fire-engine to the attention of the public.

FLAX-MILLS have been constructed in great variety: but one of the best we are acquainted with is described in *Gray's Experienced Millwright*, in nearly the following terms:

Fig. 1. pl. XVI. is the *plan*. AA, the water-wheel. CC, the shaft or axle upon which it is fixed. BB, a wheel fastened upon the same shaft, containing 102 teeth, to drive the pinion D, having 25 teeth, which is fixed upon the middle bruising-roller: E, a pinion in which are 10 teeth, turned by the wheel B, which is fastened upon the under end of the perpendicular shaft that carries the scutchers. MM, the large frame that supports one end of the shaft C, and the perpendicular axle. NN are frames in which the rollers turn that break or bruise the rough flax. IA and L, the machine and handle to raise the sluice when the water is to be let on the wheel AA to turn it round. GG, doors on the side-walls of the mill-house. IK, windows to lighten the house. HH, stairs leading up to the loft.

Fig. 2. *Elevation*. AA, the water-wheel upon its shaft CC, on which shaft the wheel BB is also fixed: this latter wheel containing 102 teeth, to turn the wheel E, having 25 teeth, which is fastened upon the middle bruising-roller. FF is a vertical shaft, upon the lower end of which is fixed a pinion having 10 teeth, which is driven by the wheel B. There are two arms that pass through the shaft F; and upon these arms are fastened, with screwed iron bolts, the scutchers that clear the refuse off the flax. DD, the frames which support one end of the axle C, the vertical shaft, and the breaking rollers: L, a weight suspended by a rope, the other end of which is fastened to a bearer, as is seen in fig 3. SS a lever, the short arm of which is attached to the frame that the gudgeons of the upper roller turn in; and by pushing down the long arm, the upper roller is, when necessary, so raised as to be clear of the middle one. NN, the end walls of the mill-house. RR, the couples or frame of the roof. H, a door in the side-wall. IK, windows.

Fig. 3. *Section.* AA, the great water-wheel fixed upon its shaft, and containing 40 aws or float-boards to receive the water which communicates motion to the whole machinery. BB, a wheel fastened upon the same axle, having, as before mentioned, 102 cogs, to drive the wheel C of 25 teeth which is fixed upon the middle roller, No. 1. The thick part of this roller is fluted, or rather has teeth all round its circumference. These teeth are of an angular form, being broad at their base, and thinner towards their outward extremities, which are a little rounded, to prevent them from cutting the flax as it passes through betwixt the rollers. The other two rollers Nos. 2. and 3. have teeth in them of the same form and size as those in the middle roller, whose teeth, by taking into those of these two rollers, turns them both round. The rough flax is made up into small parcels, which being introduced betwixt the middle and upper rollers, pass round the middle one; and this either having rollers placed on its off side, or being inclosed by a curved board that turns the flax out betwixt the middle and under rollers, when it is again put in betwixt the middle and upper one, round the same course, until it be sufficiently broken or softened, and prepared for the scutching machine. The bearer in which the gudgeon of the roller No. 1. turns is fixed on the frame at c; and the gudgeons of the rollers Nos. 2. and 3. turn in sliders that move up or down in grooves in the frames SS. The under roller is kept up to the middle one by the weights DD, suspended by two ropes going over two sheeves in the frames SS; their other ends being fastened to a transverse bearer below the sliders in which the gudgeons of the roller No. 3. turn. The weights DD must be considerably heavier than the under roller and sliders, in order that its teeth may be pressed in betwixt the teeth of No. 1. to bruise the flax when passing between the rollers. The whole weight of the roller No. 2. presses on the flax which passes between it and No. 1. There is also a box fixed on the upper edge of its two sliders to contain a parcel of stones, or lumps of any heavy metal, so that more or less weight can be added to the roller as is found necessary. OO, is the large frame that supports one end of the shaft which carries the two wheels A, B, and vertical axle FF; on the lower end of which is fixed the pinion turned by the wheel B, and having 10 teeth. In the axle F are arms upon which the scutchers are fastened with screwed bolts, as seen at GG, fig. 2. These scutchers are inclosed in the cylindrical box EE, having in its curved surface holes or porches at which the handfuls of flax are held in, that they may be cleaned by the revolving scutchers. HH, the fall or course of the water. TT, the sluice, machine, and handle, for raising the sluice to let the water on the great wheel. The gudgeons

of the axles should all turn in cods or bushes of brass. KK, the side-walls of the mill-house. GG, doors. LL, windows.

FLOUR-MILLS are put into motions in various ways: sometimes the first mover is wind, at others water, at others the force of steam, at others the muscular energy of animals. See *Foot-mill*, *Hand-mill*, *Wind-mill*, &c.

The mechanism of the grinding part of most of these is nearly the same, and well understood: so that it will not be necessary to enter much into minutiæ, but merely to present a general description of a well-constructed mill, with any first mover; and subjoin to this description some remarks, rules, and tables.

In plate XVII. we have given a section of a *double* Flour-mill, reduced from Gray's Experienced Millwright, with the following account. AA, the water-wheel. BB, its shaft or axle. CC, a wheel fixed upon the same shaft, containing 90 teeth or cogs, to drive the pinion No. 1. having 23 teeth, which is fastened upon the vertical shaft D. No. 2. a wheel fixed upon the shaft D, containing 82 teeth, to turn the two pinions FF, having 15 teeth, which are fastened upon the iron axles or spindles that carry the two upper mill-stones. EE, the beam or sill that supports the frame on which the under mill-stones are laid. GG, the cases or boxes that enclose the upper mill-stones; they should be about 2 inches distant from the stone all round its circumference. TT, the bearers, called *bridges*, upon which the under end of the iron spindles turn. These spindles pass upward through a hole in the middle of the nether mill-stones, in which is fixed a wooden bush that their upper ends turn in. The top part of the spindles, above each wooden bush, is made square, and goes into a square hole in an iron cross, which is admitted into grooves in the middle and under-surface of the upper mill-stone. By this means that stone is carried round along with the trundles FF, when turned by the wheel No. 2. One end of the bridges TT is put into mortises in fixed bearers, and the other end into mortises in the bearers that move at one end on iron bolts, their other ends hanging by iron rods having screwed nuts, as UU; so that when turned forward or backward they raise or depress the upper mill-stones, according as the miller finds it necessary. SS, the feeders, in the under end of each of which is a square socket that goes upon the square of the spindles above the iron cross or rind, and having three or four branches that move the spout or shoe, and feed the wheat constantly from the hoppers into the hole or eye of the upper mill-stone, where it is introduced betwixt the stones; and by the circular motion of the upper stones acquires a centrifugal force; and proceeding gradually from the eye of

the mill-stone towards the circumference, is at length thrown out in flour or meal. RR, the sluice, machine, and handle, to raise the sluice, and let the water on the wheel A to drive it round. No. 3. is a wheel fixed upon the shaft D, containing 44 teeth, to turn the pinion No. 4, having 15 teeth, which is fastened upon the horizontal axle H. On this axle is also fixed the barrel K, on which go the two leather belts that turn the wire engine and bolting mill. L, an iron spindle, in the under end of which is a square socket that takes in a square on the top of the gudgeon of the vertical shaft D. There is a pinion M, of 9 teeth, fixed on the upper end of the spindle L, to turn the wheel MM, having 48 teeth, which is fastened upon the axle round which the rope ZZ rolls, to carry the sacks of flour up to the cooling benches. By pulling the cord OO a little, the wheel MM and its axle are put into motion, in consequence of that wheel and its axle being moved horizontally, until the teeth of the wheel are brought into contact with those of the pinion at the top of the spindle L: and, on the contrary, by pulling the cord PP, the wheel M and its axle are moved in the opposite horizontal direction, till they are thrown out of geer with the pinion, and the rotatory motion of that wheel stops. But when the sack of flour is raised up to the lever Q, it pushes up that end of the lever, and of course the other end down; by which means the pinion M is disengaged, and thus that part of the machine stops of itself. NN are two large hoppers, into which the clean wheat is put to be conveyed down to the hoppers SS, placed on the frame immediately above the mill-stones. WW, the side-wall of the mill-house. V, the couples or frame of the roof. XX, windows to lighten the house.

Fig. 1. in the margin represents the surface of the under grinding mill-stone; the way of laying out the roads or channels; the wooden bush fixed into the hole in its middle, in which the upper end of the iron spindle turns round; and the case or hoops that surround the upper one, which ought to be two inches clear of the stone all round its circumference.

Fig. 2. the upper grinding mill-stone, and iron cross or rind in its middle; in the centre of which is a square hose that takes in a square on the top of the iron spindle, to carry round the mill-stone. When the working sides or faces of the mill-stones are laid uppermost, the roads (or channels) must lie in the same direction in both; so that when the upper stone is turned over, and its surface laid upon the under one, then the channels may cross each other, which assists in grinding and throwing out the flour; the sharp edges of the two furrows then cutting against each other like scissors. The roads are likewise laid out according to the way the upper stone revolves. In those represented

in the figures the running mill-stone is supposed to turn "*sun-way,*" or as in what is called a *right-handed* mill: but if the stone revolves the other way the channels must be cut the reverse of this, and then the mill is termed a *left-handed* one.

The elevation of this mill may be seen in Gray's Millwright, pl. XXXI.

It will not be expected that we should allot much space to the *theory* of flour-mills, though it may not be advisable to pass it over entirely. We shall therefore give two or three theorems for a single flour-mill of the common construction, which may be applied with facility, so far as they are useful, to double or triple mills.

Let the weight of the upper stone when furrowed be $= \text{W}$, the resistance of the corn reduced to the distance of the centre of gyration, or at $\frac{2}{3}$ of the radius of the upper stone $= \text{R}$, then according to Belidor, $\text{R} = \frac{\text{W}}{35}$, while according to Fabre $\text{R} = \frac{\text{W}}{23}$. But when the upper stone to work most advantageously in every respect goes round 60 times in a minute, we have

$$\text{R} = \frac{60}{\text{N}} \cdot \frac{2\text{W}}{35} = \frac{60}{450 \div \text{D}} \cdot \frac{2\text{W}}{35} = \frac{\text{DW}}{131\frac{1}{4}}$$

This, however, would require an upper mill-stone of about $7\frac{1}{2}$ feet diameter: for when the diameter of that stone is D in feet, and N the most advantageous number of rotations in 1 minute, we have, from many observations, $\text{N} = \frac{450}{\text{D}}$, as introduced into the preceding theorem; and this, when $\text{N} = 60$, gives $\text{D} = 7\frac{1}{2}$.

Let the whole friction when reduced to $\frac{2}{3}$ of the radius of the upper stone be represented by F, and the effective distance of the force or power from the axe on which the stone revolves $= r$, the number of teeth in the first or commanding wheel $=$ M, and the number of staves in the trundle $= m$, the number of revolutions of the water-wheel in 1 minute $= n$, the power which at the distance r from the axe of the water-wheel is necessary to retain the whole load in equilbrium $= p$; so shall we have

$$rp = \frac{\text{M}}{m} \cdot \frac{2}{3}\,\text{D}\,(\text{R} + \text{F})$$

$$\text{whence, } p = \frac{2\text{MD}}{3mr}\,(\text{R} + \text{F})$$

$$\text{or, because } \frac{\text{M}}{m} = \frac{\text{N}}{n}$$

$$\text{we have } p = \frac{2\text{ND}}{3nr}\,(\text{R} + \text{F}).$$

Let the time in seconds in which the water-wheel revolves be $= t$, the velocity with which any point in its circumference

moves $= v$, the height due to this velocity being $= h$, $\pi = 3{\cdot}141593$, and $g = 16\frac{1}{12}$ feet, then is

$$t = \frac{2\pi r}{v} = \frac{\pi r}{\sqrt{gh}}, \text{ and } n = \frac{60}{t} = \frac{60\sqrt{gh}}{\pi r}$$

$$\text{But it is also } n = \frac{m}{\text{M}}\,\text{N} = \frac{m}{\text{M}} \cdot \frac{450}{\text{D}}$$

$$\text{therefore } \frac{450m}{\text{DM}} = \frac{60\sqrt{gh}}{\pi r}, \text{ and } r = \frac{10\text{DM}\sqrt{gh}}{450\pi m}$$

An undershot-wheel produces the greatest useful effect, when the height due to the velocity of the impinging water being H, we have $h = \frac{1}{5}\text{H}$, or $v : \text{V} :: \sqrt{\frac{1}{5}} : 1 :: 1 : 2{\cdot}24$ nearly: retaining these as sufficiently exact for practice, the most advantageous radius of the undershot water wheel, the water pushing against shovels or float-boards, is

$$\varrho = \frac{60\text{DM}\sqrt{(\frac{1}{5}g\text{H})}}{450\pi\text{M}} = \frac{0{\cdot}019\text{DM}\sqrt{g\text{H}}}{m}$$

$$\text{or again } \varrho = \frac{{\cdot}0101\text{DMV}}{m}.$$

where V is the velocity of the impinging water.

But in undershot-mills the fall is seldom, if ever, more than 15 or 16 feet: in that case the most advantageous position of the work is to have

$$\frac{\text{M}}{m} = \frac{122{\cdot}27}{\text{DV}}.$$

Further, let L = the number of pounds of meal which are produced every hour, s = the specific gravity of the upper mill-stone, that of water being unity, and B the solid content of the stone in cubic feet: the remaining letters having the same acceptation as before; then

$$\text{for rye and wheat L} = 0{\cdot}021\text{D}^2s\text{B}\,\frac{\text{M}v}{mr} \text{ pounds.}$$

$$\text{for old barley L} = 0{\cdot}06\text{D}^2s\text{B}\,\frac{\text{M}v}{mr} \text{ pounds.}$$

Mr. Ferguson has made some practical observations on mills, which, as they are not far from coincidence with the preceding theorems, may be introduced here.

When the diameter of the upper stone is about 6 feet, as is generally the case, the lower is about an inch more: the upper stone then contains about $22\frac{1}{2}$ cubic feet, and weighs rather more than 19000 pounds. A stone of this kind ought never to revolve more than 60 or 70 times in a minute; for a more rapid motion would heat the meal. Nor must the water-wheel be too large, for in that case its angular motion will be too slow; on the contrary, if the wheel be too small, it will be deficient in moving power: 18 feet diameter is recommended as a proper

o 2

medium. And Mr. Ferguson, on the supposition that the floats of the wheel ought to move with a third part of the velocity of the water—a supposition, however, which is not strictly consistent either with theory or with Mr. Smeaton's experiments (see vol. I. arts. 473. 483, &c.)—gives the following rules for constructing the chief parts of the mill.

1. Measure the perpendicular height of the fall of water in feet above that part of the wheel on which the water begins to act, and call that the height of the fall.

2 Multiply this constant number 64·2882 (or rather $64\frac{1}{3}$) by the height of the fall in feet, and extract the square root of the product, which will be the velocity of the water at the bottom of the fall, or the number of feet the water moves per second.

3. Divide the velocity of the water by 3; and the quotient will be the velocity of the floats of the wheel in feet per second.

4. Divide the circumference of the wheel in feet, by the velocity of its floats; and the quotient will be the number of seconds in one turn or revolution of the great water-wheel, on the axis of which is fixed the cog-wheel that turns the trundle.

5. Divide 60 by the number of seconds in one turn of the water-wheel or cog-wheel; and the quotient will be the number of turns of either of these wheels in a minute.

6. Divide 60 (the number of turns the mill-stone ought to have in a minute) by the above-said number of turns; and the quotient will be the number of turns the mill-stone ought to have for one turn of the water or cog wheel. Then,

7. As the required number of turns of the mill-stone in a minute is to the number of turns of the cog-wheel in a minute, so must the number of cogs in the wheel be to the number of staves or rounds in the trundle on the axis of the mill-stone, in the nearest whole number that can be found.

By these rules the following table is calculated; in which the diameter of the water-wheel is supposed 18 feet, and consequently its circumference $56\frac{4}{7}$.

The Millwright's Table.

Perpendicular height of the fall of water.	Velocity of the water in feet per second.	Velocity of the wheel in feet per second.	Number of turns of the wheel in a minute.	Required number of turns of the millstone for each turn of the wheel.	Nearest num. of cogs and staves for that purpose		Number of turns of the millstone for one turn of the wheel by these cogs and staves.	Number of turns of the millstone in a min. by these cogs and staves.
					Cogs.	Staves.		
1	8·02	2·67	2·83	21·20	127	6	21·17	59·91
2	11·40	3.78	4·00	15·00	105	7	15·00	60·00
3	13·89	4·63	4·91	12·22	98	8	12·25	60·14
4	16·04	5·35	5·67	10·58	95	9	10·56	59.87
5	17·93	5·98	6·34	9·46	85	9	9·44	59·84
6	19·64	6·55	6·94	8·64	78	9	8·66	60·10
7	21·21	7·07	7·50	8·00	72	9	8·00	60·00
8	22·68	7·56	8·02	7·48	67	9	7·44	59·67
9	24·05	8·02	8·51	7·05	70	10	7·00	59·57
10	25·35	8·45	8·27	6·39	67	10	6·70	60·09
11	26·59	8·86	9·40	6·38	64	10	6·40	60·16
12	27·77	9·26	9·32	6·11	61	10	6·10	59·90
13	28·91	9·64	10·22	5·87	59	10	5·80	60·18
14	30·00	10·00	10·60	5·66	56	10	5·60	59·36
15	31·05	10·35	10·99	5·46	55	10	5·40	60·48
16	32·07	10·69	11.34	5·29	53	10	5·30	60.10
17	33·06	11·02	11·70	5.13	51	10	5·10	59·67
18	34·02	11·34	12·02	4.99	50	10	5·00	60·10
19	34·95	11·65	12·37	4.85	49	10	4·80	60·61
20	35·86	11·92	12·68	4.73	47	10	4·70	59·59

Mr. Fenwick, the author of "Essays on Practical Mechanics," made a numerous set of experiments on some of the best mills for grinding corn, in order to form a set of tables illustrative of the effect of a given quantity of water, in a given time, applied on an overshot water-wheel of a given size. His observations, tables, and examples, will form the remaining part of this article.

The quantity of water expended on the water-wheel was measured with great exactness; the corn used was in a medium state of dryness; the mills, in all their parts, were in a medium working state; the millstones, making from 90 to 100 revolutions per minute, were from $4\frac{1}{2}$ to 5 feet in diameter.

The result of the experiments was, that the power requisite to raise a weight of 300lbs. avoirdupois, with a velocity of 190 feet per minute, would grind 1 boll of good rye in 1 hour; but, for the sake of making the following tables hold in practice, where imperfection of construction exists in some small degree, it is taken at 300lbs. raised with a velocity of 210 feet per minute, (being 1-10th more); and for grinding 2, 3, 4, or 5

bolls of rye per hour requires a power equal to that which could raise 300lbs. with the velocity of 350, 506, 677, or 865 feet per minute respectively. The difference of the power requisite to grind equal quantities of wheat from that for rye will be very trifling.

The power required to raise a weight of 300lbs. avoirdupois, with a velocity of 390 feet per minute, will prepare properly 1 ton of old rope per week, for the purpose of making paper; and for preparing, in like manner, 2 tons of the same kind of materials per week, requires a power able to raise 300lbs. with a velocity of 525 feet per minute, the mill working from 10 to 12 hours per day.

A SET OF TABLES, *showing the quantity of water (ale measure) requisite to grind different quantities of corn, from* 1 *to* 5 *bolls (Winchester measure) per hour, applied on overshot water-wheels, from* 10 *to* 32 *feet diameter; also the size of the cylinder of the common steam-engine to do the same work.*

The water-wheel, 10 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	786	12·5
1½	1056	14·6
2	1341	16·75
2½	1617	18·5
3	1894	20·2
3½	2220	21·75
4	2541	23·25
4½	2891	24·75
5	3242	26·25

The water-wheel, 12 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	655	12·5
1½	873	14·6
2	1091	16·75
2½	1343	18·5
3	1576	20·2
3½	1840	21·75
4	2117	23·25
4½	2408	24·75
5	2700	26·25

The water-wheel, 11 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	705	12·5
1½	945	14·6
2	1188	16·75
2½	1454	18·5
3	1723	20·2
3½	2014	21·75
4	2306	23·25
4½	2626	24·75
5	2944	26·25

The water-wheel, 13 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	606	12·5
1½	806	14·6
2	1009	16·75
2½	1234	18·5
3	1458	20·2
3½	1705	21·75
4	1952	23·25
4½	2223	24·75
5	2494	26·25

The water-wheel, 14 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	564	12·5
1½	740	14·6
2	927	16·75
2½	1140	18·5
3	1353	20·2
3½	1583	21·75
4	1811	23·25
4½	2060	24·75
5	2306	26·25

The water-wheel, 15 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	535	12·5
1½	710	14·6
2	894	16·75
2½	1090	18·5
3	1290	20·2
3½	1503	21·75
4	1717	23·25
4½	1967	24·75
5	2211	26·25

The water-wheel, 16 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	491	12·5
1½	650	14·6
2	811	16·75
2½	993	18·5
3	1176	20·2
3½	1380	21·75
4	1582	23·25
4½	1802	24·75
5	2023	26·25

The water-wheel, 17 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	458	12·5
1½	628	14·6
2	770	16·75
2½	943	18·5
3	1117	20·2
3½	1300	21·75
4	1482	23·25
4½	1695	24·75
5	1906	26·25

The water-wheel, 18 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	440	12.5
1½	595	14·6
2	730	16·75
2½	860	18·5
3	1054	20·2
3½	1227	21·75
4	1400	23·25
4½	1600	24·75
5	1800	26·25

The water-wheel, 19 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	411	12·5
1½	550	14·6
2	690	16·75
2½	845	18.5
3	1000	20·2
3½	1165	21·75
4	1330	23·25
4½	1517	24·75
5	1707	26·25

The water-wheel, 20 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	392	12·5
1½	530	14 6
2	675	16·75
2½	808	18·5
3	945	20.2
3½	1110	21·75
4	1270	23·25
4½	1445	24·75
5	1623	26·25

The water-wheel, 21 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	370	12·5
1½	500	14.6
2	635	16·75
2½	767	18.5
3	900	20·2
3½	1060	21·75
4	1212	23.25
4½	1379	24·75
5	1547	26·25

The water-wheel, 22 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	350	12.5
1½	473	14·6
2	594	16·75
2½	722	18·5
3	860	20·2
3½	1007	21·75
4	1153	23·25
4½	1313	24·75
5	1472	26·25

The water-wheel, 23 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	338	12·5
1½	454	14·6
2	570	16·75
2½	707	18·5
3	824	20·2
3½	964	21·75
4	1124	23·25
4½	1258	24.75
5	1412	26·25

The water-wheel, 24 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	327	12·5
1½	436	14·6
2	545	16·75
2½	671	18·5
3	788	20·2
3½	920	21·75
4	1055	23·25
4½	1204	24·75
5	1350	26·25

The water-wheel, 25 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	316	12·5
1½	418	14·6
2	520	16·75
2½	635	18·5
3	752	20·2
3½	876	21·75
4	985	23·25
4½	1150	24.75
5	1300	26·25

The water-wheel, 26 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	303	12·5
1½	403	14·6
2	504	16·75
2½	617	18·5
3	730	20·2
3½	852	21.75
4	975	23·25
4½	1111	24·75
5	1247	26.25

The water-wheel, 27 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	293	12·5
1½	385	14·6
2	482	16·75
2½	593	18·5
3	703	20·2
3½	822	21·75
4	940	23·25
4½	1070	24·75
5	1200	26·25

The water-wheel, 28 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	282	12·5
1½	370	14·6
2	463	16·75
2½	570	18·5
3	676	20·2
3½	791	21·75
4	905	23·25
4½	1030	24·75
5	1153	26·25

The water-wheel, 29 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	274	12·5
1½	363	14·6
2	455	16·75
2½	557	18·5
3	660	20·2
3½	770	21·75
4	880	23·25
4½	1005	24·75
5	1130	26·25

The water-wheel, 30 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	267	12·5
1½	355	14·6
2	447	16·75
2½	545	18·5
3	645	20·2
3½	750	21·75
4	858	23·25
4½	983	24·75
5	1106	26·25

The water-wheel, 31 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	256	12·5
1½	340	14·6
2	426	16·75
2½	520	18·5
3	620	20·2
3½	717	21·75
4	827	23·25
4½	940	24·75
5	1058	26·25

The water-wheel, 32 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	245	12·5
1½	325	14·6
2	406	16·75
2½	496	18·5
3	588	20·2
3½	690	21·75
4	791	23·25
4½	900	24·75
5	1012	26·25

To make the foregoing tables applicable to mills intended to be turned by undershot or breast water-wheels: from Smeaton's experiments it appears, that the power required on an undershot water-wheel, to produce an effect equal to that of an overshot (to which the tables are applicable), is as 2·4 to 1; and also the power required on a breast water-wheel, which receives the water on some point of its circumference, and afterwards descends on the ladle boards, to produce an equal effect with an overshot water-wheel, is as 1·75 to 1.

A Table, *showing the necessary size of the cylinder of a common steam-engine to grind different quantities of corn, from* 1 *to* 12 *bolls (*4 *to* 48 *bushels Winchester measure) per hour.*

Bolls of corn ground per hour.	Diameter of the cylinder, in inches.
1	12·3
1½	14·6
2	16·75
2½	18·5
3	20·2
3½	21·75
4	23·25
4½	24·75
5	26·25
5½	27·25
6	28·1
6½	29
7	29·8
7½	31·1
8	32
8½	33·3
9	34·2
9½	35·2
10	36
10½	37·3
11	38
11½	38·85
12	39·5

N. B. This table will be applicable to any improved steam-engine, as well as that of the common kind, if the ratio of their efficacies is known.

Application of the tables.

Example I.—If a stream of water, producing 808 gallons ale measure per minute, can be applied on an overshot water-wheel 20 feet diameter, what quantity of corn will it be able to grind per hour?

Look in the tables under a 20 feet water-wheel, and opposite 808 gallons will be found $2\frac{1}{2}$ bolls of corn ground per hour.

Example II.—If a stream of water, producing 808 gallons ale measure per minute, can be applied to an undershot water-wheel 20 feet diameter, what quantity of corn can it grind per hour?

It is found by the tables, that if applied on an overshot water-wheel 20 feet diameter, the stream will grind $2\frac{1}{2}$ bolls per hour; and, from page 202, the power required by the undershot to that of the overshot water-wheel, to produce an equal effect, is as 2·4 to 1; therefore, as 2·4 : 1 :: 2·5 : 1·04 bolls of corn ground per hour by means of the stream.

Example III.—If a stream of water, producing 808 gallons ale measure per minute, can be applied on a breast water-wheel 20 feet diameter, what quantity of corn can it grind per hour?

It is found by the tables, that, if applied on an overshot water-wheel of equal size, $2\frac{1}{2}$ bolls of corn will be ground per hour; and, from page 202, the power of a breast water-wheel to that of an overshot water-wheel, to produce an equal effect, is as 1·75 to 1; therefore, as 1·75 : 1 :: 2·5 : 1·42 bolls of corn ground per hour by the stream.

Example IV.—Of what diameter must the cylinder of a common steam engine be made, to grind 10 bolls of corn per hour?

By looking in the table, page 202, opposite 10 bolls ground per hour, the diameter of the steam cylinder will be found to be 36 inches.

FLY, is a name given to a certain appendage to many machines, either as a *regulator* of their motions, or as a *collector* of power. When used as a regulator, the fly is commonly a heavy disk or hoop balanced on its axis of motion, and at right angles to it: though sometimes a regulating fly consists of vanes or wings, which as they are whirled round meet with considerable resistance from the air, and thus soon prevent any acceleration in the motion: but this kind of regulator should rarely, if ever, be introduced in a working machine, as it wastes much of the moving force. When the fly is used as a collector of power, it is frequently seen in the form of heavy knobs at the opposite

ends of a straight bar; as in the coining-press. In arts. 18..23. of the introductory part of this volume the reader will find several remarks on the nature and operation of the different kinds of flies used in machines.

FOOT-MILL, is a mill for grinding corn or any other substance, moved by the pressure of the feet of men or animals In some foot-mills, a horse or an ox is fixed to a stall upon a floor above a vertical wheel; and a hole is made in the floor in the place where the hind feet of the animal should stand, thus admitting those feet to press upon the rim of a wheel, and cause the wheel to turn upon its axle, and give motion to the whole mill. But in this kind of machine the animal will be obliged very unnaturally to move his hind feet while his fore feet will be at rest: and further, the motive force being applied near the vertex of the wheel will act but with little advantage; and the work done will be comparatively trifling.

A much more judicious construction of a foot-mill is given in *G. A. Bockler's Theatrum Machinarum*, published at Nuremburgh, in 1661. This mill is represented in fig. 1. pl. XV. A is an inclined wheel, which is turned by the weight of a man, and the impulsive force of his feet while he supports himself, or occasionally pushes with his hands at the horizontal bar H. The face of this wheel has thin pieces of wood nailed upon it at proper distances, to keep the feet of the man from slipping while he pushes the wheel round; and the under side has projecting teeth or waves which catch into the cogs of the trundle B, and by that means turn the horizontal shaft G with its wheel C: this latter wheel turns the trundle D, the axle of which carries the upper millstone E. This kind of footmill will answer extremely well to grind malt, &c. when no very great power is required. The advantages and disadvantages of the inclined wheel have been stated under the article CRANE, when describing the contrivance of Mr. White, which is the same as this of Bockler's with respect to the wheel.

FORCER, TEMPORARY, for a pump, is a contrivance to produce a constant stream. A very simple forcer of this kind has been devised by Mr. R. Trevithick: it consists in fixing a barrel with a solid piston along the side of the common pump, in such a manner, that the lower space of the additional barrel may communicate with the space between the two valves of the pump; and, lastly, by connecting the rods so that they may work together. This is shown in fig. 1. plate IX.; and the effect is, that when the pistons are raised, the spaces beneath, A and B, become filled by the pressure of the atmosphere, at the same time that the upper column flows out at E. But again, when the pistons descend, the valve C shuts, and consequently,

the water driven by the piston in B must ascend through A, and continue to produce an equal discharge through E in the down stroke. (*Nich. Journ.* No. 7. N. S)

FOUNTAIN, HERO'S. See HYDRAULIC *machines*. No. 6.

GIBBET, or JIB, of a crane, the projecting beam, upon the extremity of which is fixed a pulley for the rope to pass over that raises the weight: it is represented by DEF, in fig. 3. pl: IX. Jibs of the usual construction turn on two solid gudgeons. The rope by which the goods are raised passes over the upper gudgeon, and is confined between two small vertical rollers, in order that it may constantly lead fair with the pulley or sheave at the extremity of the jib. According to this construction, whenever the crane turns round its axis, the rope is bended so as to form an angle more or less acute, which causes a great increase of friction, and produces a continual effort to bring the arm of the jib into a parallel position to the inner part of the rope. These inconveniences may appear to be trifling on paper, but in actual practice they are of no small importance, for they necessarily imply a much greater exertion of power in raising goods, and the application of a constant force to keep the jib in the position that may be requisite; while the partial stress which is exerted on only a few strands of the rope, when bended into an acute angle, infallibly destroys it in a very short time.

The simple construction proposed by Mr. J. Bramah obviates all these defects, and at the same time possesses the very desirable property of permitting the jib of what is termed a camp-shut or landing crane wholly to revolve round its axis, and to land goods at any point of the circle described by the arm of the jib.

It consists in perforating the axis or pillar of the crane, and in conducting the rope through this perforation by means of an additional pulley fixed on the top of the arm of the jib. The rope proceeds from the goods which are hoisted, through a pulley fixed as usual at the extremity of the jib; it then passes over another pulley fixed at the opposite extremity of the jib, and is by this pulley conducted through the perforated axis or pillar to a third pulley; whence it is immediately directed to the crane by which the weight is elevated.

It is almost unnecessary to state that the lower axis is usually fixed in an oil box, and that friction rollers are applied to the axis wherever the circumstances may render it necessary.

When great weights are to be raised, as large stones from a quarry, or pieces of ordnance from a ship to a quay, the crane is commonly a fixed one, and only the gibbet moveable, from which the weight hangs. Here, in the common way of working a crane, the rope of which runs between two vertical rollers, there is often much danger in turning the gibbet upon its axis.

A small rope, called a guide-rope, is fastened to the weight, or to the upper part of the gibbet near its extremity, which a man pulls to bring the weight over the place where it is to be lowered. Now, in performing this, the main rope not continuing parallel to the arm of the gibbet, gives the weight a tendency towards that side to which it deviates, and that sometimes so suddenly, that without care and much force applied, the load will swing with great violence, and do much mishief. To prevent this, Mr. *Ralph Allen* of Bath, about the year 1728, recommended the following method: Upon the shaft of the gibbet let there be fixed an iron wheel with several teeth or cogs, to be carried round by a pinion fixed upon a horizontal axis, such axis passing through the wall or frame-work behind the shaft of the gibbet, and having at its further extremity a vertical wheel with handles projecting from the rim in the plane of the wheel. A man standing at this wheel is out of the reach of danger from the load, and by applying a small portion of his strength at the handles of the wheel he can easily bring the gibbet and its load to any position required, and retain it as long as necessary in that position. A figure representing this contrivance is given in the Phil. Trans. No. 411. and in Ferguson's Select Lectures.

GIMBALS, a contrivance by means of which barometers, vessels of oil, mariner's compasses, &c. may be suspended so as to arrange their upper parts horizontally. The nature of this contrivance will be at once understood by showing its application to a mariner's compass. It consists of a hoop or ring supported upon two pins diametrically opposite each other, and issuing from the external surface of the ring in such a direction that both lie in the same diametrical line. When the hoop is suspended on these pins it is at liberty to turn freely about the diameter of which they constitute the prolongation. The notches or holes of support are disposed horizontally. The compass-box itself is placed in a similar ring with two projecting pivots; and these pivots are inserted in holes made in the former ring at equal distances from each of *its* pivots. If therefore the whole be left at liberty, the compass-box may vibrate upon the diametral line of the outer ring, as well as upon a line formed by its own pivots, at right angles to that diametral line. The consequence of this arrangement is, that the centre of gravity of the compass-box will dispose itself immediately beneath the intersection of both lines on which it is at liberty to move:—that is to say, if the weight of the box and its component parts be properly disposed, the compass will assume a position in which the upper surface shall be horizontal.

GIN. See CRAB.

GLAZIERS'S VICE, is an instrument for drawing window

lead. See fig. 3. pl. XII. PG, QH, are two axles running in the frame KL, ML. C, D, two wheels of iron case-hardened, $1\frac{1}{2}$ inch broad, and of the thickness of a pane of glass; these wheels are fixed to the axles, and run very near one another, their distance not exceeding $\frac{1}{10}$ of an inch: across their edges several nicks are cut, the better to draw the lead through. E, F, are two pinions each of twelve leaves, turning one another and going upon the ends of the axles, which are square, being kept fast there by the nuts P, Q, which are screwed fast with a key. A, B, are two cheeks of iron, case-hardened, and fixed on each side to the case with screws; these are cut with an opening where the two wheels meet, and set so near to the wheels as to leave a space equal to the thickness of the lead; so that between the wheels and the cheeks there is left a hole of the form represented at N, which is the shape of the lead when cut through. The frame KLML is held together by cross bars passing through the sides, and screwed on: and a cover is put over the machine to exclude the dust. The whole is screwed down fast to a bench by screw nails LL. When the vice is used, the lead to be drawn is first cast in moulds, into pieces a foot long, with a gutter on each side. One of these pieces is taken, and an end of it sharpened a little with a knife; then being put into the hole between the wheels, by turning the handle I the lead is drawn through the vice, and receives the form designed.

GOVERNOR, a contrivance for the purpose of equalizing the motion of mills and other machinery.

When a part of the machinery of a mill is suddenly stopped, or suddenly set going, and the moving power remains the same, an alteration in the volocity of the mill will take place; it will move faster or slower. Every machine having a certain velocity at which it will work at greater advantage than at any other, the change of velocity arising from the above cause is in all cases a disadvantage, and in delicate operations exceedingly hurtful. In the case of a cotton-mill, for instance, which is calculated to move the spindles at a certain rate, if from any cause the velocity is much increased, a loss of work immediately takes place, and an increase of waste from the breaking of the threads, &c.; on the other hand, there must be an evident loss from the machinery moving too slow.

In steam-engines this evil is remedied by a contrivance called a *governor*. (See fig. 1. pl. XL.)—"Two balls are fixed to the ends of rods, in continual revolution, and as soon as the motion becomes a little too rapid, the balls rise considerably," and, by the intervention of a lever, act upon a *throttle-valve*, which diminishes the quantity of steam admitted, and of course serves to make the motion less rapid.

1. *The steam-engine governor.*—IK, fig, 1. represents a spindle kept in motion by the engine; A, B, the centrifugal balls; CA, and CB, the rods by which the balls are suspended. These rods cross one another, and pass through the middle of the spindle at C. There is a round pin put through the spindle and the rods at C, which serves as the point of suspension for the centrifugal balls or revolving pendulum. There is a part of the spindle above C, which is square, and nicely polished, so that the piece of brass, M, may slide easily up and down upon it. The piece of brass M is round on the outside, and has an external groove turned upon the upper end of it to receive the lever NO, the fulcrum of which is at P. This piece of brass is connected with the ball-rods by two short pieces and joints DE, FG.

The construction of steam-engine governors sometimes differs a little from that now described; but if this particular construction be understood, there will be no difficulty in comprehending any other in use.

Operation.—When the engine goes too fast, the balls fly off from the spindle, and depress the end, N, of the lever, which partly shuts the throttle-valve, and thereby diminishes the quantity of steam admitted into the cylinder; and, on the other hand, when the engine goes too slow, the balls fall down toward the spindle, and elevate the end N, of the lever, which partly opens the throttle-valve, and thereby increases the quantity of steam admitted into the cylinder. The theory of the conical pendulum is given in art. 288, vol. I.

2. In a wind-mill, when the velocity is increased by the irregular action of the wind, the corn is sometimes forced rapidly through the mill without being sufficiently ground. There is an elegant contrivance for preventing this (similar to the governor of a steam-engine), but which was much earlier in use, called in some parts of England a *lift-tenter*, "By means of the centrifugal force of one or more balls, which fly out as soon as the velocity is augmented, and allow a lever to rise with them, and cause the upper millstone to descend and bring it a little nearer to the lower one."

This machine is curious, and might perhaps in other cases be usefully applied. We shall, therefore, describe two constructions, both on the same principles.

Life-Tenters for Wind-mills.—First Construction. This machine, and part of the stone-spindle and framing with which it is connected, are represented in fig. 3. pl. XL.

To the stone-spindle there are fixed four arms A, A, A, A; there are four similar arms B, B, B, B, firmly attached to the hollow cylinder C, which is loose on the spindle FG.

The pendulums D, D, D, D, are hung above, to the arms

A, A, A, A, and through holes toward their lower extremities pass the arms of the loose cylinder.

When the mill is at rest, the pendulums hang vertically; but, by their centrifugal force, when the mill is in motion they hang obliquely; and that obliquity is increased in proportion to the velocity, and proportionately raises the loose cylinder C.

This cylinder C acts on the one end of the lever E, which has a connexion with the clove upon which the bridge of the stone spindle rests, and accordingly raises or depresses the upper millstone in proportion as the wind is weak or strong.

Second Construction. Another modification of the same principle (applied above the *mill-stones,*) but having one pendulum only, is represented by fig. 4. and will be easily understood from what has been said respecting the first construction.

3. Governors are sometimes applied to water-wheels, and made on various constructions. Smiths' bellows have been applied to that use, the upper board rising or falling in proportion to the velocity of the lower board, which received its motion from the mill. But we shall proceed to describe a construction which has for several years been at work in Cartside cotton-mill, which was erected under the direction of the late Robert Burns, Esq.

Water-wheel Governor.—First Construction. The principles of this kind of water-wheel governor are nearly the same as those of the governor of a steam-engine. It has a revolving pendulum which receives its motion from the mill, and in proportion as the machinery moves faster or slower, the centrifugal force acts upon the governor and raises or depresses an iron cross, which, acting on a lever, reverses the motion by the wheel work, which operates upon a sluice so as to enlarge or lessen the passage of the water to the water-wheel; this sluice is made on the principles of the *throttle-valve,* in order that it may be moved by a small power. So long as the machinery is moving at a proper velocity, this wheel-work of the sluice apparatus remains at rest.

Fig. 5. represents different views of this machine, and some of its parts detached. The same letter in all the figures refers to the same part.

The revolving pendulum EFGH, receives its motion from the mill-work by means of a rope giving motion to a pulley I. The upright shaft MN is kept in constant motion by the wheel-work OPRS. The wheel N acts constantly into the two bevelled wheels T and U, and makes them move in contrary directions. They are loose on the shaft when the mill is going at its proper speed.

But if the mill moves either too fast, or too slow, the one of

these wheels, by means of a clutch Q, in a way to be described, is connected with, and carries round, the lying shaft DC, and, by a pair of bevelled wheels, communicates motion to the oblique shaft BW; which again, by a screw X, and quadrant-wheel Y, moves the sluice Z, and by making it stand more or less oblique, alters the area of the passage for the water.

From inspecting fig. 5. No. 1. it will be evident that the box *a*, will be raised or depressed, in proportion as the balls E and F, of the revolving pendulum EFGH, are further or nearer to the centre of motion; when the velocity is greatest, the balls E and F, by their centrifugal force, will extend themselves furthest from the centre of motion, and raise the box *a*. See also fig. 5. No. 2. No. 3. and No. 4.

To the box *a*, is fixed a cross *bc*. There is a forked lever *dqe*, the fulcrum of which is at *f*, and which turns horizontally. This forked lever has four prongs 1, 2, 3, 4.

When the mill is at its proper speed, the cross works within the prongs 1 and 2; in this situation of the forked lever, the clutch Q is disengaged from both the wheels T and U, and they move on their bushes without carrying round the lying shaft. The clutch is made to slide on a part of the shaft which is square.

When the mill goes too quick, the cross gland is raised, and, in turning round, strikes the prong 3, which immediately causes the lever to throw the clutch into the arms of the wheel U, which then carries the clutch and shaft round with it, and by the means already described, acts on the sluice, and by lessening the quantity of water falling on the wheel, diminishes its speed.

On the other hand, when the mill goes too slow, the cross is depressed, and, striking the prong 4, reverses the motion of the shaft, and so produces a contrary effect on the sluice.

It may be proper to remark, that the train of wheel-work is so calculated as very much to reduce the motion at the sluice, and it is found from experience, that this is necessary. Were the area of the aperture too suddenly changed, the effect on the water wheel would be too violent. Every time the mill is stopped, it is proper to lift the wheel R out of gear. The centre on which the sluice turns should be one third of its height from the bottom, in order that the pressure of the water above the centre may balance that below.

At *m* there is an upright shaft, which is worked by hand when required.

Water-wheel Governor.—Second Construction. Fig. 6. represents a sluice regulator as executed in some parts of England. It differs little from that already described, only that the lying-shaft AB receives its motion immediately from the mill,

instead of from the axle of the revolving pendulum, as in the first construction. From having so minutely described that construction, the attentive reader will find no difficulty in comprehending fig. 6. from inspecting the plate.

These ingenious contrivances, with the illustrative diagrams, are extracted from "Buchanan's Essays on Mill Work," where other constructions for like purposes may be seen.

GRAVIMETER, the name given by M. Guyton to an instrument for measuring specific gravities: he adopts this name rather than either areometer or hydrometer, because these latter terms are grounded upon the supposition that the liquid is always the thing weighed; whereas, with regard to solids, the liquid is the known term of comparison to which the unknown weight is referred.

Guyton's gravimeter is executed in glass, and is of a cylindric form, being that which requires the smallest quantity of fluid, and is on that account preferable, except so far as it is necessary to deviate for the security of a vertical position. Like Nicholson's Hydrometer (art. 404. vol. I.) it carries two basins; one of them superior, at the extremity of a thin stem, towards the middle of which the fixed point of immersion is marked. The other, or lower basin, terminates in a point; it contains the ballast, and is attached to the cylinder by two branches. The moveable suspension by means of a hook has the inconvenience of shortening the lever which is to secure the vertical position.

The cylinder is 22 millimeters (0·71 inch) in diameter; and 21 centimeters (6·85 inches) in length. It carries in the upper basin an additional constant weight of 5 grammes (115 grains). These dimensions might be increased so as to render it capable of receiving a much more considerable weight; but this is unnecessary. M. Guyton has added a piece which he calls the *plongeur*, because in fact it is placed in the lower basin when used, and is consequently entirely immersed in the fluid. It is a bulb of glass loaded with a sufficient quantity of mercury, in order that its total weight may be equal to the constant additional weight, added to the weight of the volume of water displaced by this piece. It will be readily understood that the weight being determined at the same temperature at which the instrument was originally adjusted, it will sink to the same mark on the stem, whether it be loaded with a constant additional weight in the upper basin, or whether the effect of this weight be produced by the additional piece in the lower dish. From this explanation there will be no difficulty in seeing how this instrument may be adapted to every case in practice.

It may be used 1. for solids. It differs not in this respect from Nicholson's hydrometer. The only condition will be, as in his instrument, that the absolute weight of the body to be examined shall be rather less than the constant additional weight, which in this instrument is 5 grammes, or 115 grains.

2. For liquids of less specific gravity than water, the instrument, without the additional weight above mentioned, weighs about 2 decagrammes (459 grains) in the dimensions before laid down. It would be easy to limit its weight to the utmost accuracy. We have therefore the range of one-fifth of buoyancy, and consequently the means of ascertaining all the intermediate densities from water to the most highly rectified spirit of wine, which is known to bear in this respect the ratio of 8 to 10 with regard to water.

3. When liquids of greater specific gravity than water are to be tried, the constant weight being applied below, by means of the additional piece, which weighs about 6 grammes (138 grains), the instrument can receive in the upper basin more than 4 times the usual additional weight, without losing the equilibrium of its vertical position. In this state it is capable of showing the specific gravity of the most concentrated acids.

4. It possesses another property common to Nicholson's instrument, namely, that it may be used as a balance to determine the absolute weight of such bodies as do not exceed its additional load.

5. Lastly, the purity of the water being known, it will indicate the degrees of rarefaction and condensation in proportion to its own bulk.

This instrument may be readily constructed by any workman in glass. The additional piece for the lower basin will require some attention to make it perfectly agree with the constant upper weight, as to the immersion of the instrument: But this object may, by careful adjustment, be ascertained with the utmost certainty and accuracy. The bulb of glass is for this purpose drawn out to a fine point, a sufficient quantity of mercury is then introduced to sink it, and the aperture closed with a little piece of wax. The bulb being then placed in the lower basin of the instrument, the upper basin is to be loaded until the mark on the stem becomes accurately coincident with the surface of the water. The sum of the weights added above is precisely equal to that of the quantity of mercury necessary to be added to that in the glass bulb; which done, nothing more is needed than to seal the point by fusion, taking care not to change its bulk.

The whole is rendered portable by means of a case in which all the delicate parts are secured from pressure, and the heavier

parts supported in such a manner as to resist the excess of motion they are capable of acquiring by virtue of their mass. This last circumstance is frequently overlooked by such workmen as are employed in the package of instruments; whence it necessarily follows, that some strain or fracture must be produced when matters of very unequal density are exposed to receive a common impulse.

To find the specific gravity of any solid by the gravimeter, observe this rule: "From the weight in the upper dish, when the instrument is properly immersed in the unknown fluid, take the weight which is placed with the body in the same scale at the like adjustment. The remainder is the absolute weight of the solid. Multiply this by the specific gravity of the fluid, and reserve the product. From the additional weight when the body is placed in the lower basin, take the weight when it was placed in the upper. The remainder will be the loss of weight by immersion. Divide the reserved product by the loss by immersion, and the quotient will be the specific gravity of the solid with regard to distilled water at the standard temperature and pressure."

To find the specific gravity of a fluid proceed thus: "To the weight of the gravimeter add the weight required in the upper basin to sink it in the unknown fluid. Again, to the weight of the gravimeter add the weight required in the same manner to sink it in distilled water. Divide the first sum by the latter, and the quotient will be the specific gravity of the fluid in question."

For figures of the gravimeter, see *Annales de Chimie*, tome 21, or Nicholson's Journal, vol. I. 4to.

GUDGEONS, in machinery, having all the weight on the shaft to support, ought to be made sufficiently strong for that purpose; while, to avoid unnecessary friction, they should be made as small in diameter as possible, consistently with the requisite strength and durability.

Wrought iron being stronger than cast iron in about the ratio of 7 to 5, will bear a greater weight; yet, cast iron being cheaper, and more easily shaped, is more frequently employed for gudgeons.

Mr. Buchanan, who has paid considerable attention to this subject, gives these rules for the gudgeons of water-wheels.

1. The cube-root of the weight of a water-wheel *in hundred weights*, is nearly equal to the *diameter in inches*, of a *cast-iron* gudgeon sufficiently strong to support such wheel.

2. For *wooden* water-wheels, multiply the diameter *in feet* by the width also *in feet*, to which add the square of *half the*

diameter: the cube root of the sum will be nearly equal to the diameter of the gudgeon *in inches*.

These, of course, must be regarded as approximations.

Mr. Buchanan has inferred from several experiments, that "gudgeons of the same size, of cast and of wrought iron, are capable, at a medium, of sustaining weights without flexure, in the proportion of 9 to 14."

Upon this principle Mr. B. computed the following table, to show the proportionate diameters of cast-iron and wrought-iron gudgeons.

Explanation of the table of cast-iron and wrought-iron gudgeons.

Column 1 and 2 are the same as those in the table of cast-iron gudgeons.

Column 3 contains numbers in the proportion of 9 to 14 less than those in column 2.

Column 4 contains the cube root of column 3, or the diameters of wrought-iron gudgeons, having the same strength as those of cast-iron in column 1.

USE OF THE TABLE.

Example.

To find the diameter of a wrought-iron gudgeon of the same strength with one of cast-iron of 3 inches diameter. Look on the first column for 3, and on the same line on the 4th column will be found 2·571282, that is, a little more than $2\frac{1}{2}$ inches, the diameter required of the wrought-iron gudgeon.

The numbers in the 3d column, being the cube of those in the 4th, another use may be made of this part of the table. For, supposing the 4th column to represent cast iron gudgeons, the 3d column will represent the hundred weights which cast-iron gudgeons of those diameters should sustain.

Table of Cast and Wrought-iron Gudgeons.

1	2	3	4
Diameter of cast-iron gudgeons in inches.	Cube of diameter of cast-iron gudgeons or the cwts. which the gudgeons may sustain.	Cube of diameter of wrought-iron gudgeons.	Diameter of wrought-iron gudgeons in inches and parts.
1·	1·	·6428571	·362054
1·25	1·953125	1·2555803	1·063340
1·5	3·375	2·1696427	1·259921
1·75	5·359375	3·4453125	1·514825
2·	8·	5·1428571	1·709976
2·25	11·400625	7·3289732	1·912933
2·5	15·625	10·0446428	2·154435
2·75	20·796875	13·3694196	2·351335
3·	27·	17·3571428	2·571282
3·25	34·328125	22·0670803	2·802039
3·5	42·875	27·5625	3·018294
3·75	52·734375	33·9006696	3·239612
4·	64·	41·1428571	3·448217
4·2	76·765625	49·3493303	3·659306
4·5	91·125	58·5803571	3·881936
4·7	107·171875	68·896	4·101566
5·	125·	80·357	4·308870
5·25	144·763125	93·023	4·530655
5·5	166·375	106·955	4·747459
5·75	190·109375	122·213	4·959675
6·	216·	138·857	5·180101
6·25	244·140625	156·948	5·394690
6·5	274·625	176·545	5·609376
6·75	307·546875	197·709	5·828476
7·	343·	220·500	6·041377
7·25	381·078125	244·979	6·257324
7·5	421·875	271·205	6·471274
7·75	465·484375	299·240	6·686882
8·	512·	329·143	6·903436
8·25	561·515625	360·975	7·120367
8·5	614·125	394·795	7·337234
8·75	669·921875	430·664	7·553688
9·	729·	468·643	7·769462
9·25	791·453125	508·791	7·984344
9·5	875·375	562·741	8·257263
9·75	926·859375	595·837	8·415541
10·	1000·	642·857	8·631103
10·25	1076·890625	692·287	8·845085
10·5	1157·625	744·187	9·061309
11·75	1242·296875	798·619	9·279308
11·	1331·	855·643	9·493599

(*Buchanan on the Shafts of Mills.*)

HANDMILLS, are commonly used for some culinary purposes, as the grinding of coffee, pepper, and the like. Sometimes handmills of larger size are used to grind malt, wheat, &c. and in such cases the hand is generally applied to a winch handle. But in *Bockler's Theatrum Machinarum* there is a description of a mill, in which the effort of a man is applied to a lever moving to and fro horizontally, nearly as in the action of rowing: as this is a very advantageous method of applying human strength, the effort being greatly assisted by the heaviness of the man in leaning back, we shall give a brief description of this kind of mill, which is represented in fig. 4. pl. XII. The vertical shaft EG carries a toothed wheel C, and a solid wheel F; the latter being intended to operate as a regulating fly. Upon the crank AB hangs one end of an iron bar I, the other end of which hangs upon the lever HK; the motion being pretty free at both ends of this bar I. One end of the lever HK hangs upon the fixed hook K, about which as a centre of motion it turns. Then, while a man, by pulling at the lever HK, moves the extremity H from H to N, the bar I acting upon the crank AB gives to the wheels C and F half a rotation; and the momentum they have acquired will carry them on, the man at the lever suffering it to turn back from N to H, while the other half of the rotation of the wheels is completed. In like manner another sufficient pull at the lever HK gives another rotation to the wheel C, and so on, at pleasure. The wheel C turns by its teeth the trundle D, the spindle of which carries the upper mill-stone, just as the spindle D carries round the upper stone in fig. 1. pl. XV.

In this mill the nearer the end of the bar I upon the lever HK is to the fixed hook K, the easier, *cæteris paribus,* will the man work the mill. If the number of teeth in the wheel C be 6 times the number of cogs in the trundle D, then the labourer by making 10 pulls at the lever H in a minute will give 60 revolutions to the upper mill-stone in the same space of time.

The Society of Arts have lately adjudged a silver medal to Mr. Garnet Terry, of City Road, Finsbury-square, for his invention of a mill to grind hard substances, by means of a wheel turning upon a horizontal axis instead of a vertical one, as in the common construction. Mr. Terry has constructed this mill on a large scale; there is also a model deposited in the collection of that society.

Plate VIII. fig. 4. A. The hopper or receptacle of the articles which are intended to be ground.

B. A spiral wire, in the form of a reversed cone, to regulate the delivery of them.

C. An inclined iron plate, hung upon a pin on its higher end; the lower end rests on the grooved axis D, and agitates the wire B.

D. The grooved axis, or grinding cylinder, which acts against the channelled iron plate E.

F. A screw on the side of the mill, by means of which the iron plate E is brought nearer to or removed further from the axis D, according as the article is wanted finer or coarser.

G. The handle by which motion is given to the axis.

H. The tube from whence the articles, when ground, are received.

*** The front of the mill is taken off, in order to show its interior construction.

HEART-WHEEL is the name given in England to a well known method of converting a circuitous motion into an alternating rectilinear one, which is common in cotton-mills. It is an ellipse turned either on an axle, or by means of a winch and handle on one of its foci, or its centre, on whose edge a moveable point or circle presses; the latter receives an alternating motion from the circumference of the ellipse, and presses it in its revolution to different distances from the centre of motion. This method was contrived, we believe, by Sir Samuel Morland, about the year 1685. The practical disadvantages of this contrivance are the inequality of pressure and of moving force which will be required at different parts of the rotation of the ellipse, and the consequent wearing of some parts of it much faster than others, which will render it frequently necessary to have new elliptical wheels. A late application of the heart-wheel has been already mentioned, under the word COINING.

HOOKE'S JOINTS, or, as they are often called, *universal* joints, have been described in the introductory part of this volume.

HYDRAULIC MACHINES, are structures contrived for the purpose either of conveying water from one situation to another, particularly from a lower to a higher; or, by means of the force or pressure of water, to perform some mechanical operation, as grinding, boring, sawing. The former kind of hydraulic engines will principally be spoken of here; the latter being described under the various heads FLOUR-MILL, FLAX-MILL, SAW-MILL, &c.

1. Of all the machines the ancients invented to raise water, it appears that though Archimedes's screw (see *Archimedes's* SCREW in this volume) was the most curious, the *tympanum*, mentioned by Vitruvius, elevated the greatest quantity at once: a brief description of this may suffice, as preparatory to the ac-

count of a machine made in imitation of it, but more ingenious and more perfect.

The *tympanum* is a great hollow wheel, forming a kind of barrel or drum (as its name imports), composed of several planks joined together, well calked and pitched, and having a horizontal axle on which it turns: the interior of this drum is divided into 8 equal spaces by as many partitions placed in the directions of the radii; each space or cell has an orifice of about half a foot in the rim of the drum or wheel, so shaped as to facilitate the admission of the water: moreover, there are 8 hollow channels running contiguous to each other and parallel to the axle of the wheel, each corresponding to one of the 8 large cells; into these channels the water passes out of the cells just mentioned, and, after running along the channels to a convenient distance, it escapes through orifices into a reservoir placed just under the axle. Thus the water is elevated through a vertical space equal to the radius of the hollow wheel. When the tympanum is used to raise water from a running stream, it is moved by means of float boards which are impelled by the stream: but when it is employed to raise stagnant water, there is commonly a smaller wheel on the same shaft, which is turned by men walking in it, as in the old walking crane. The chief defect of this machine is that it raises the water in the most disadvantageous situation possible: for the load being found always toward the extremity of a radius of the wheel, the arm of the effective lever which answers to it, increases through the whole quadrant the water describes in passing from the bottom of the wheel to the altitude of its centre; so that the power must act in like manner as if it were applied at a winch handle, and cannot, therefore, act uniformly.

2. To remedy this defect M. *de la Faye* devised a machine which may here be described, together with the process of reasoning that led to it.

When we develope the circumference of a circle, a curve is described (i. e. the *involute*) of which all the radii are so many tangents to the circle, and are likewise all respectively perpendicular to the several points of the curve described, which has for its greatest radius a line equal to the periphery of the circle evolved. The truth of which is shown by geometricians when treating of the genesis of evolute and involute curves.

Hence, having an axle whose circumference a little exceeds the height which the water is proposed to be elevated, let the circumference of the axle be evolved, and make a curved canal whose curvature shall coincide throughout exactly with that of the involute just formed: if the further extremity of this canal

be made to enter the water that is to be elevated, and the other extremity abut upon the shaft which is turned; then in the course of the rotation the water will rise in a vertical direction, tangential to the shaft, and perpendicular to the canal in whatever position it may be. Thus the action of the weight answering always to the extremity of a horizontal radius will be as though it acted upon the invariable arm of a lever, and the power which raises the weight will be always the same: and if the radius of the wheel, of which this hollow canal serves as a bent spoke, is equal to the height that the water is to be raised, and consequently equal to the circumference of the axle or shaft, the power will be to the load of water reciprocally as the radius of a circle to its circumference, or directly as 1 to $6\frac{1}{4}$ nearly.

In M. *de la Faye's* opinion, the machine ought to be composed of four of these canals: but it has often been constructed with 8, as represented in fig. 1. pl. XIX. The wheel being turned by the impulsion of the stream upon the float-boards, the orifices F, E, D, C, &c. of the curvilinear canals, dip one after another into the water which runs into them: and as the wheel revolves the fluid rises in the canals *f, e, d, c,* &c. and runs out in a stream P from the holes at O; it is received into the trough Q, and conveyed from thence by pipes.

By this construction the weight to be raised offers always the same resistance, and that the least possible, while the power is applied in the most advantageous manner the circumstances will admit of: these conditions both fulfilled at the same time furnish the most desirable perfection in a machine. Further, this machine raises the water by the shortest way, namely the perpendicular, or vertical; in this respect being preferable to Archimedes's screw, where the water is carried up an inclined path; and besides this, each curved channel in this wheel empties all the water it receives in every revolution, while the screw of Archimedes delivers only a small portion of the fluid it is charged with, being often loaded with 20 times as much water as is discharged in one rotation; and thus requiring an enormous increase of labour when a large quantity is intended to be raised by it.

The nature and advantages of this wheel evince very forcibly how far the speculations of geometers are from being so unfruitful in useful applications, as is often insinuated by practical men.

3. The wheel just described would we think be the most perfect of any that could be employed for raising water, had it not the disadvantage attending the tympanum, which is, that it can only raise water to the height of its semidiameter. As in many

cases water is to be raised higher than the radius of any wheel can well be made for practice, we shall next describe a machine called the *Noria*, common in Spain, which raises water nearly through a diameter. This Noria consists of a vertical wheel of 20 feet diameter, on the circumference of which are fixed a number of little boxes or square buckets, for the purpose of raising the water out of the well, communicating with the canal below, and to empty it in a reservoir above, placed by the side of the wheel. The buckets have a lateral orifice, to receive and to discharge the water. The axis of this wheel is embraced by four small beams, crossing each other at right angles, tapering at the extremities, and forming eight little arms. This wheel is near the centre of the horse-walk contiguous to the vertical axis, into the top of which the horse-beam is fixed; but near the bottom it is embraced by four little beams, forming eight arms, similar to those above described, on the axis of the water-wheel. As the mule which they use goes round, these horizontal arms, supplying the place of cogs, take hold each in succession, of those arms which are fixed on the axis of the water-wheel, and keep it in rotation.

This machine, than which nothing can be cheaper, throws up a great quantity of water; yet undoubtedly it has two defects; the first is, that part of the water runs out of the buckets and falls back into the well after it has been raised nearly to the level of the reservoir: the second is, that a considerable proportion of the water to be discharged is raised higher than the reservoir, and falls into it only at the moment when the bucket is at the highest point of the circle, and ready to descend. These inconveniences are both remedied by the contrivance mentioned in the next paragraph.

4. The *Persian wheel* is a name given to a machine for raising water, which may be turned by means of a stream AB acting upon the wheel CDE according to the order of the letters: (fig. 1. pl. XIX.) The buckets *a*, *a*, *a*, *a*, &c. instead of being firmly fastened, are *hung* upon the wheels by strong pins, *b*, *b*, *b*, *b*, &c. fixed in the side of the rim; which must be made as high as the water is intended to be raised above the level of that part of the stream in which the wheel is placed. As the wheel turns, the buckets on the right hand go down into the water, where they are filled, and return up full on the left hand, till they come to the top at K; where they strike against the end *n* of the fixed trough M, by which they are overset, and so empty the water into the trough; from whence it is to be conveyed in pipes to any place it is intended for; and as each bucket gets over the trough, it falls into a perpendicular position again, and so goes down empty till it comes to the water at A, where it is

filled as before. On each bucket is a spring *r*, which going over the top or crown of the bar *m* (fixed to the trough M) raises the bottom of the bucket above the level of its mouth, and so causes it to empty all its water into the trough.

To determine the due relation of the power and the weight so that this wheel may be capable of producing the greatest effect, the following may be taken as a good approximation. After having fixed the diameter of the wheel, which must be something greater than the altitude to which the water is to be raised; fix also upon an even number of buckets to be hung at equal distances round the periphery of the wheel, and mark the position of their centres of motion in such a manner that they will stand in corresponding positions in every quarter of the circle: conceive vertical lines drawn through the centre of motion of each bucket in the rising part of the wheel; they will intersect the horizontal diameter of the wheel in points at which if the buckets were hung they would furnish the same resistance to the moving force as they do when hanging at their respective places on the rim of the wheel. Thus, supposing there were 18 equidistant buckets; then while 8 hung on each side a vertical diameter of the wheel there would be 8 on the other side, and 2 would coincide with that diameter; in this case the resistance arising from all the full buckets would be the same as if one bucket hung on the prolongation of the horizontal diameter at the distance of $2 \sin 20^0 + 2 \sin 40^0 + 2 \sin 60^0 + 2 \sin 80^0$, these being the sines to the common radius of the wheel.

To know the quantity of water that each bucket should contain, take $\frac{4}{9}$ of the absolute force of the stream, that is, $\frac{4}{9}$ of the weight of the prism of water whose base is the surface of one of the float-boards, and whose height is that through which water must fall to acquire the velocity of the stream: so have we the power that should be in equilibrio with the weight of water in the buckets of the rising semicircle. Then say, as the sum of the sines mentioned above is to radius, so is the power just found to a fourth term, the half of which will be the weight of water that ought to be contained in one bucket. Lastly, as the velocity of the wheel will be to that of the stream nearly as 1 to $2\frac{2}{5}$, the quantity of revolutions it makes in any determinate time becomes known, and of consequence, the quantity of water the wheel will raise in the same time; since we know the capacity of each bucket, and the number of them emptied in every revolution of the wheel.

5. Another mechanical contrivance for the purpose of raising water is a *chain-pump*. This is now generally made from 12 to 24 feet in length; consists of two collateral square barrels, and

an endless chain of pistons of the same form fixed at proper distances. The chain is moved round a coarse kind of wheel-work, fixed sometimes at one end, but often at both ends of the machine. The teeth of the wheel-work are so contrived as to receive one half of the flat pistons and let them fold in; and they take hold of the links as they rise. A whole row of the pistons (which go free of the sides of the barrel by about a quarter of an inch) are always lifting when the pump is at work; and, as this machine is generally worked briskly, the pistons or pallets bring up a full bore of water in the pump. Chain-pumps are wrought sometimes by men turning winches, sometimes by horses, and sometimes by the impulse of a stream of water: they are likewise so contrived that by the continual folding in of the pistons, stones, dirt, or whatever comes in the way, may be cleared off: they are therefore often used to drain ponds, sewers, and remove foul water, when no other pump could be employed.

Chain pumps are not merely fixed in a vertical position, but are often inclined; and in the latter case they are in a state of the greatest perfection, or raise the most water, when the breadth of the pallets is equal to their distance from each other, and the plane is inclined under an angle of 24° 21′.

It is not unusual for chain-pumps to be erected without a barrel to receive the pistons, after the manner represented in fig. 3. pl. XIX. The pallets are converted into square boxes *s*, *s*, &c. which are raised by means of hexagonal axles, each side of the hexagon being equal to the distance from box to box: the boxes descend with their mouths downwards, and so enter the water.

Another contrivance for raising water similar to the chain-pump is an endless rope with stuffed cushions hung upon it, which, by means of two wheels or drums, are caused to rise in succession in the same barrel, and to carry water with them. From the resemblance of this apparatus to a string of beads, it is usually called *paternoster-work*. But in this, as well as the chain-pump, the magnitude of the friction is a formidable practical objection.

6. Jets and fountains are not now considered as conducive to picturesque beauty; nor can they be reckoned of much utility, except perhaps in hot climates: we have not therefore described any in this work. But in the fountain of *Hero* of Syracuse a principle is introduced which has been found of great utility in larger works; for the head of water is actually lower than the orifice, but the pressure is communicated by the intervention of a column of air: the construction of this fountain is as follows. It consists of two vessels KLMN (fig. 5. pl. XIX.) and OPQR.

which are close on all sides. A tube AB, having a funnel at the top, passes through the uppermost vessel without communicating with it, being soldered into its top and bottom. It also passes through the top of the under vessel, where it is likewise soldered, and reaches almost to its bottom. This tube is open at both ends. There is another open tube ST, which is soldered into the top of the under vessel, and the bottom of the upper vessel, and reaches almost to its top. These two tubes serve also to support the upper vessel. A third tube GF is soldered into the top of the upper vessel, and reaches almost to its bottom. This tube is open at both ends, but the orifice G is very small. Now suppose the uppermost vessel filled with water to the height EN, E*e* being its surface a little below T. Stop the orifice G with the finger, and pour in water at A. This will descend through AB, and compress the air in OQRP into less room. Suppose the water in the under vessel to have acquired the surface C*c*, the air which formerly occupied the whole of the spaces OPQR and KL*e*E will now be contained in the spaces OP*c*C and KL*e*E; and its elasticity will be in equilibrio with the weight of the column of water whose base is the surface E*e*, and whose height is A*c*. As this pressure is exerted in every part of the air, it will be exerted on the surface E*e* of the water of the upper vessel; and if the pipe FG were continued upwards, the water would be supported in it to a height *e*H above E*e*, equal to A*c*. Therefore, if the finger be now taken from off the orifice G, the fluid will spout up through it to the same height as if it had fallen through a tube whose altitude is *e*H. So long as there is any water in the vessel KLNM there will be a discharge through the orifice: therefore the play of the fountain will continue whilst the water contained in the upper vessel, having spouted out, falls down through the pipe AB: the height of the water measured from the basin VAW to the surface of the water in the lower vessel OPQR is always equal to the height measured from the top of the jet to the surface of the water in the vessel KLMN. Now, since the surface E*e* is always falling, and the water in the lower vessel always rising, the height of the jet must continually decrease, till it is shorter by the depth of LKNM, which is empty, added to the depth of OPQR, which is always filling; and when the jet is fallen so low it immediately ceases to play.

7. A machine designed to raise water to a great height for the irrigation of land, in such situations as have the advantage of a small fall, is described in Dr. Darwin's *Phytologia:* as it depends on the principle of Hero's fountain, it may properly be inserted here.

Fig. 4 pl XIX. *a, b*, is the stream of water.

b, *c*, *c*, represents the water-fall, supposed to be 10 feet.

d, *e*, are two leaden or iron vessels, containing a certain quantity of water, which may be computed to be about 4 gallons each.

f, *g*, *h*, *i*, *k*, *l*, are leaden vessels, each holding about two quarts.

o, *p*, two cocks, each of which passes through two pipes, opening the one and closing the other.

q, *r*, is a *water-balance*, that moves on its centre *s*; and by which the two cocks *o* and *p* are alternately turned.

t, *u*, and *w*, *x*, are two air pipes of lead, both internally one inch and a quarter in diameter.

y, *z*; *y*, *z*; *y*, *z*; are water-pipes, each being one inch in diameter.

The pipe *b*, *c*, *c*, is always full from the stream *a*, *b*; the small cisterns *g*, *i*, *l*, and the large one *d*, are supposed to have been previously filled with water. The fluid may then be admitted by turning the cock *o*, through the pipe *c*, *e*, into the large cistern *e*. This water will press the air confined in the cistern *e*, up the air-pipe *w*, *x*, and will force the fluid out of the cisterns *g*, *i*, *l*, into those marked *h*, *k*, and *c*. At the same time, by opening B, the water and condensed air, which previously existed in the large cistern *d*, and in the smaller ones marked *f*, *h*, *k*, will be discharged at B. After a short time, the water-balance, *q*, *r*, *s*, will turn the cocks, and exclude the water, while it opens the opposite ones: the cisterns *f*, *h*, *k*, are emptied in their turns by the condensed air from the cistern *d*, as the water progressively enters the latter from the pipe *b*, *c*.

8. A very ingenious application of the same principle has been made in the celebrated Hungarian machine, at Chemnitz. The best account we have been able to obtain of this is the following.

In fig. 3. pl. XVIII. A represents the source of water elevated 136 feet above the mouth of the pit. From this there runs down a pipe D of four inches diameter, which enters the top of a copper cylinder B, $8\frac{1}{2}$ feet high, 5 feet diameter, and 2 inches thick, and reaches to within 4 inches of the bottom: it has a cock at I.*

This cylinder has a cock at Q, and a very large one at N. From its top proceeds a pipe VEC two inches in diameter, which goes 96 feet down the pit, and is inserted into the top of another brass cylinder C,* which is $6\frac{1}{2}$ feet high, 4 feet diameter, and

* In the figure these vessels are in form of parallelopipeds, and there are some pipes and cocks which are not referred to in this description: but this happens, because one diagram is made to serve for both the original machine and Mr. Boswell's improvements mentioned directly after.

two inches thick: the latter containing about 83 cubic feet, which is nearly one half of the capacity of the former, viz. 170 cubic feet. There is another pipe FO of 4 inches diameter, which rises from within 4 inches of the bottom of this lower cylinder, is soldered into its top, and rises to the trough Z which carries off the water from the mouth of the pit. This lower cylinder communicates at the bottom with the water O, which collects in the drains of the mines. A large cock P serves to exclude or admit this water: another cock M at the top of this cylinder communicates with the external air.

Now, suppose the cock I shut, and all the rest open: the upper cylinder will contain air, and the lower cylinder will be filled with water, because it is sunk so deep that its top is below the usual surface of the mine-waters. Shut the cocks Q, N, M, P, and open the cock I. The water of the source A must run in by the orifice J, and rise in the upper cylinder, compressing the air above it and along the pipe VEC, and thus acting on the surface of the water in the lower cylinder. It will therefore cause it to rise gradually in the pipe OF, where it will always be of such a height that its weight balances the elasticity of the compressed air. Suppose no issue given to the air from the upper cylinder, it would be compressed into one-fifth of its bulk by the column of 136 feet high; for a column of 34 feet nearly balances the ordinary elasticity of the air. Therefore, when there is an issue given to it through the pipe VEC, it will drive the compressed air along this pipe, and it will expel water from the lower cylinder. When the upper cylinder is full of water, there will be 34 cubic feet of water expelled from the lower cylinder. If the pipe OP had been more than 136 feet long, the water would have risen 136 feet, being then in equilibrio with the water in the feeding pipe D by the intervention of the elastic air; but no more water would have been expelled from the lower cylinder than what fills this pipe. But the pipe being only 96 feet high, the water will be thrown out at Z with a considerable velocity. If it were not for the great obstructions which water and air must meet with in their passage along pipes, it would issue at Z with a velocity of more than fifty feet per second. It issues however much more slowly, and at last the upper cylinder is full of water, and the water would enter the pipe VE and enter the lower cylinder, and, without displacing the air in it, would rise through the discharging pipe OF, and run off to waste. To prevent this there hangs in the pipe VE a cork ball or double cone, by a brass wire which is guided by holes in two cross pieces in that pipe. When the upper cylinder is filled with water, this cork plugs up the orifice V, and no water is wasted; the influx at J now stops. But the lower

cylinder contains compressed air, which would balance water in a discharging pipe 136 feet high, whereas O P is only 96. Therefore the water will continue to flow at Z till the air has so far expanded as to balance only 96 feet of water, that is, till it occupies one-half of its ordinary bulk, that is, one-fourth of the capacity of the upper cylinder, or $42\frac{1}{2}$ cubic feet. Therefore $42\frac{1}{2}$ cubic feet will be expelled, and the efflux at Z will cease; and the lower cylinder is about one-half full of water. When the attending workman observes this, he shuts the cock I. He might have done this before, had he known when the orifice V was stopped; but no loss ensues from the delay. At the same time the attendant opens the cock N, the water issues with great violence, being pressed by the condensed air from the lower cylinder. It therefore issues with the sum of its own weight and of this compression. These gradually decrease together, by the efflux of the water and the expansion of the air; but this efflux stops before all the water has flowed out; for there are $42\frac{1}{2}$ feet of the lower cylinder occupied by air. This quantity of water remains, therefore, in the upper cylinder nearly: the workman knows this, because the discharged water is received first of all into a vessel containing three-fourths of the capacity of the upper cylinder. Whenever this is filled, the attendant opens the cock P by a long rod which goes down the shaft; this allows the water of the mine to fill the lower cylinder, and the air to get into the upper cylinder, which permits the remaining water to run out of it. Thus every thing is brought into its first condition; and when the attendant sees no more water come out at N, he shuts the cocks N and M, and opens the cock I, and the operation is repeated.

There is a very surprising appearance in the working of this engine. When the efflux at Z has stopped, if the cock Q be opened, the water and air rush out together with prodigious violence, and the drops of water are changed into hail or lumps of ice. It is a sight usually shown to strangers, who are desired to hold their hats to receive the blasts of air: the ice comes out with such violence as frequently to pierce the hat like a pistol bullet. This rapid congelation is a remarkable instance of the general fact, that air by suddenly expanding generates cold, its capacity for heat being increased.

The above account of the procedure in working this engine shows that the efflux both at Z and N becomes very slow near the end. It is found convenient therefore not to wait for the complete discharges, but to turn the cocks when about 30 cubic feet of water have been discharged at Z: more work is done in this way. A gentleman of great accuracy and knowledge of these subjects took the trouble of noticing particularly the per-

formance of the machine. He observed that each stroke, as it may be called, took up about three minutes and one-eighth; and that 32 cubic feet of water were discharged at Z, and 66 were expended at N. The expense therefore is 66 feet of water falling 136 feet, and the performance is 32 raised 96, and they are in the proportion of 66×136 to 32×96, or of 1 to 0·3422, or nearly as 3 to 1. This is superior to the performance of the most perfect undershot mill, even when all friction and irregular obstructions are neglected; and is not much inferior to any overshot pump-mill that has yet been erected. When we reflect on the great obstructions which water meets with in its passage through long pipes, we may be assured that, by doubling the size of the feeder and discharger, the performance of the machine will be greatly improved; we do not hesitate to say, that it would be increased one-third: it is true that it will expend more water; but this will not be nearly in the same proportion, for most of the deficiency of the machine arises from the needless velocity of the first efflux at Z. The discharging pipe ought to be 110 feet high, and not give sensibly less water. Then it must be considered how inferior in original expense this simple machine must be to a mill of any kind which would raise 10 cubic feet 96 feet high in a minute, and how small the repairs on it need be, when compared with a mill. And, lastly, let it be noticed that such a machine can be used where no mill whatever can be put in motion. A small stream of water, which would not move any kind of wheel, will here raise one-third of its own quantity to the same height; working as fast as it is supplied.

For these reasons, we think that the Hungarian machine eminently deserves the attention of mathematicians and engineers, to bring it to its utmost perfection, and into general use. There are situations where this kind of machine may be very useful. Thus, where the tide rises 17 feet, it may be used for compressing air to seven-eighths of its bulk; and a pipe leading from a very large vessel inverted in it may be used for raising the water from a vessel of one-eighth of its capacity 17 feet high; or if this vessel has only one-tenth of the capacity of the large one set in the tide-way, two pipes may be led from it; one into the small vessel, and the other into an equal vessel 16 feet higher, which receives the water from the first. Thus one-sixteenth of the water may be raised 34 feet, and a smaller quantity to a still greater height; and this with a kind of power that can hardly be applied any other way. Machines of this kind are described by Schottus, Sturmius, Leupold, and other old writers; and they should not be forgotten, because opportunities may offer of making them highly beneficial.

9. Mr. John Whitley Boswell has devised an apparatus which when attached to such a machine as that at Chemnitz will enable it to work itself without attendance. The description of this will be presented to the reader in Mr. Boswell's own words.

Fig. 3. pl. XVIII. A is the reservoir, or upper level of water.

B, a chamber made of sufficient strength to bear the internal pressure of a column of water the height of A above it, multiplied by its own base.

C, a chamber of the same strength as B, but of a smaller size; it is placed at the bottom of the pit from which the water is to be raised, and under the level of the water.

These chambers would be stronger with the same materials, if of a globular or cylindrical form; but the square shape is used in the drawing merely for the facility of representing the position of the parts.

D, a pipe from the reservoir A which passes through the top of B, and ends near its bottom, to convey water from A to B.

E, a pipe from the top of B to the top of C, to convey air from B to C.

F, a pipe from the bottom of C to the level of the ground at the top of the pit, to carry off the water from the pit.

G, a pipe from the bottom of B to carry off the water from it.

H, a vessel to contain the water used in working the cocks; it is only placed on the top of B to save the construction of a stand on purpose for it.

I, a cock, or moveable valve (worked by the lever there represented), in the large pipe D.

K, a stop-cock in the small pipe which conveys water from D to H. Its use is to make the engine work faster or slower, by letting water more or less quick into H; or to stop it altogether from working when required.

L, a moveable valve or cock in the small pipe LK. The lever which works it is connected by a strong wire with the lever which works I, and is balanced by a weight at its opposite extremity, sufficient to open both these cocks and shut N, when not prevented by a counter weight.

N, a cock in the pipe G to open and shut it as wanted.

O, a self-moving valve in the pipe F, which permits the water to pass upwards, but prevents its return.

P, a self-moving valve at the bottom of C, which permits the water to pass into C, but prevents any from passing out of it; it is furnished with a grating, to prevent dirt getting in.

R, a vessel suspended from the levers of I and L, capable of containing a weight of water sufficient to shut them.

S, a vessel suspended from the lever of N: it must contain water enough by its weight to open N: it is connected by a chain to R, to keep it down as long as N is open.

T, a syphon passing from the bottom of H, near its upper edge, and down again to the mouth of R.

V, a self-moving valve of a sufficient levity to rise, when the water in B comes up to it, and close the pipe E; into which no water would else pass from B. A ball-cock, such as used in common water cisterns, would do here.

X, a syphon from the bottom of R rising within an inch of its top, and passing down again to the mouth of S.

Y, a small pipe at the bottom of S: this may have a stop-cock, to regulate it, which, when stopped, will also stop the engine.

The mode of this engine's working is as follows: suppose the vessels V, H, R, and S empty of water, and the cocks K and Y open, and the vessel C full of water. The weight on the lever of L will then open the cocks L and I, on which the water from A will flow into B and H. As the water rises in B, it will force the air through E into C, which, strongly pressing on the water in C, will force it up through the pipe F, till the water in B rises to the lever of V and closes it, at which time H will be full of water (the quantity flowing in being so regulated by the cock K), and the water will flow from it through the syphon T into the vessel R, which as it fills shuts the cocks I and L, and prevents any more water coming into B and H. When R is full, the water flows through its syphon X, which fills S, and by it opens N, which empties B of water, and keeps N open as long as there is any water in H.

When H is empty, B will be so too (being so regulated by the cock K), on which, in a moment or two, R and S will also be empty; which will cause the cocks I and L to open, and all things will be again in the state first supposed, for a repetition of the operations described.

To stop the engine, the cocks at K and Y should be shut, while S is full of water. To set it working, they should be open; and this is all the attendance it will require. As no one but an engineer should attempt to construct such an engine as this, it was useless to represent the manner of connecting the pipes by flanches or otherwise; or the proper methods of fastening and closing the parts, which are all well known to such as have made this art their study. (*Nicholson's Journal*, 4to. vol. I.)

In No. 5. of the New Series of Nicholson's Journal, Mr. Boswell has made some further improvements in the application of the Hungarian machine.

10. The *Spiral pump* is a very curious hydraulic engine, which operates on nearly the same principle as the Hungarian machine. The first engine of this kind, of which we have seen any account, was invented and erected by H. Andreas Wirtz, a tinplate-worker of Zurich, at a dye-house in Limmat, in the vicinity of that city. It consists of a hollow cylinder, like a very large grindstone, turning on a horizontal axis, and partly plunged in a cistern of water. The axis is hollow at one end, and communicates with a vertical pipe. This cylinder or drum is formed into a spiral canal, by a plate coiled up within it like the main spring of a watch in its box; only the spires are at a distance from each other, so as to form a conduit for the water of uniform width. This spiral partition is well joined to the two ends of the cylinder, and no water escapes between them. The outermost turn of the spiral begins to widen about $\frac{3}{4}$ of a circumference from the end, and this gradual enlargement continues nearly a semicircle, this part being called the horn: it then widens suddenly, forming a scoop or shovel. The cylinder is so supported that this shovel may, in the course of a rotation, dip several inches into the water. As the cylinder turns upon its axis, the scoop dips and takes up a certain quantity of water before it emerges again. This quantity is sufficient to fill the horn; and this again is nearly equal in capacity to the outermost uniform spiral round.

After the scoop is emerged, the water passes along the spiral by the motion of it round the axis, and drives the air before it into the rising pipe, where it escapes. In the mean time, air comes into the mouth of the scoop; and when the scoop again dips into the water, it again takes in some of that fluid. Thus there becomes a part filled with water, and a part filled with air. Continuing this motion, a second round of water will be received, and another of air. The water in any turn of the spiral will have its two ends on a level; and the air between the successive columns of water will be in its natural state; for since the passage into the rising pipe or main is open, there is nothing to force the water and air into any other position. But since the spires gradually diminish in their length, it is plain that the column of water will gradually occupy more and more of the circumference of each. At last it will occupy a complete turn of some spire that is near the centre; and when sent further in by the continuance of the motion, some of it will run back over the top of the succeeding spire. Thus it will run over into the right-hand side of the third spire; and consequently will push the water of this spire backwards, and raise its other end, so that *it* will likewise run over backwards *before* the next rotation be completed. At length this change of disposition

will reach the outermost spire, and some water will run over into the horn and scoop, and finally into the cistern.

But as soon as water gets into the rising pipe, and rises a little into it, it stops the escape of the air when the next scoop of water is taken in. Hence there are then two columns of water acting against each other by hydrostatic pressure, and the intervening column of air: they must compress the air between them, and the water and air columns will now be unequal: this will have a general tendency to keep the whole water back, and cause it to be higher on the left or rising side of each spire than on the right or descending side: the excess of height being just such as produces the compression of the air between that and the preceding column of water. This will go on increasing as the water mounts in the rising pipe; for the air next to the rising pipe is compressed at its inner end with a weight of the whole column in the main: and it must be as much compressed at its outer end, which must be done by the water column without it; and this column exerts this pressure partly by reason that *its* outer end is higher than its inner end, and partly by the transmission of the pressure on its outer end by air, which is similarly compressed from without. Thus it will happen that each column of water being higher at its outer than at its inner end, compresses the air on the water column beyond or within it, which transmits this pressure to the air beyond *it*, adding to it the pressure arising from its own want of level at the ends. Consequently, the greatest compression, viz. that of the air next the main, is produced by *the sum of all the transmitted pressures*; and these are the sum of all the differences between the elevations of the inner ends of the water columns above their outer ends: and the height to which the water will rise in the main will be just equal to this sum.

Suppose the left-hand spaces of each spire to be filled with water, and the right-hand spaces filled with air, as is shown, in regard to one spire, in fig. 3. pl. XVII. There is a certain gradation of compression which will keep things in this position: for the spaces manifestly decrease in arithmetical progression; and so do the hydrostatic heights and pressures: if, therefore, the air be dense in the same progression all will be in hydrostatical equilibrium. Now this may obviously be produced by the mere motion of the machine; for since the density and compression in each air column is supposed inversely as the magnitude of the column, the quantity of air is the same in all; therefore the column first taken in will pass gradually inwards, and the increasing compression will cause it to occupy precisely the whole right-hand of every spire. The gradual diminution of the water columns will be produced, during the motion, by the water

running over backwards at the top from spire to spire, and ultimately coming out by the scoop. Since the hydrostatic height of each water column is now the greatest possible, viz. the diameter of the spire, it is evident that this disposition of the air and water will raise the water to the greatest height This disposition may be obtained thus: let CB be a vertical radius of the wheel, C being the centre, and B the highest point [the figure may easily be drawn]; upon CB, take CL to CB, as the density of the external air to its density in the last column next the rising pipe or main; that is, make CL to CB as 34 feet (the height of the column of water which balances the pressure of the atmosphere), to the sum of 34 feet, and the height of the rising pipe: then divide BL into such a number of turns that the sum of their equal diameters shall be equal to the height of the main; lastly, bring a pipe straight from L to the centre C. Such is the construction of the spiral pump, as originally invented by Wirtz: it certainly indicates very considerable mechanical knowledge and sagacity.

But, when the main is very high, this construction will require either an enormous diameter of the drum, or many turns of a very narrow pipe. In such cases it will be much better to make the spiral in the form of a corkscrew, than of this flat form like a watch-spring. The pipe which forms the spiral may be wrapped round the frustum of a cone, whose greatest diameter is to the least (which is next to the rising pipe) in the proportion just assigned to CB and CL. By this construction the water will so stand in every round as to have its upper and lower surfaces tangents to the top and bottom of the spiral, and the water columns will occupy the whole ascending side of the machine, while the air occupies the descending side. This form is far preferable to the flat form: it will allow us to employ many turns of a large pipe, and therefore produce a great elevation of a large quantity of water.

The same thing will be still better accomplished by wrapping the pipe on a cylinder, and making it gradually tapering to the end, in such a manner that the contents of each spire may be the same as when it is wrapped round the cone. It will raise the water to a greater height (though certainly with an increase of the impelling power), by the same number of spires, because the vertical or pressing height of each column is greater.

In the preceding description of this machine, that construction has been chosen which made its principle and manner of working most evident, namely, that which contained the same material quantity of air in each turn of the spiral, more and more compressed as it approaches to the rising pipe. But this is not the best construction: for we see that in order to raise

water to the height of the column of 34 feet, the air in the last spire is compressed into half its space; and the quantity of water delivered into the main at each turn is but half what was received into the first spire, the rest flowing back from spire to spire, and being discharged at the spout.

But the construction may be such that the quantity of water in each spire may be the same that was received into the first; by which means a greater quantity (double in the instance now given) will be delivered into the main, and raised to the same altitude by very nearly the same force. This may be done by another proportion of the capacity of the spires; either by a change of their caliber, or of the diameters of the solid on which they are folded. Suppose the bore to be uniform throughout, the diameters must so vary that the constant column of water and the column of air, compressed to the proper degree, may occupy the whole circumference. Let A be the column of water which balances the pressure, and H the height to which the water is to be raised. Let A be to A + H as 1 to m. Then it is plain that m will represent the density of the air in the last spire, if its natural density be 1, because it is pressed by the column A + H while the common air is pressed by A. Let 1 represent the constant water column, and consequently it will be nearly equal to the air column in the first spire: then the whole circumference of the last spire must be $1 + \frac{1}{m}$, in order to hold the water 1, and to compress the air into the space $\frac{1}{m}$ or $\frac{A}{A+H}$. The circumference of the first spire is 1 + 1 or 2: and if D and d be the diameters of the first and last spires we have $2 : 1 + \frac{1}{m} :: D : d$, or $2\,m : m + 1 :: D : d$. If, therefore, a pipe of uniform bore be wrapped round a conic frustum, of which D and d are the end diameters, the spirals will be very nearly such as will answer the purpose. It will not be *quite* exact, for the intermediate spirals will be rather too large: the conoidal frustum should in strictness be formed by the revolution of a logarithmic curve. With such a spiral the full quantity of water which was confined in the first spire will soon find room in the last, and will be sent into the main at every rotation. This is a very great advantage, especially when the water is to be much raised. The saving of power by this change of construction is always proportional to the greatest compression of the air.

The chief difficulty in any of these forms is in determining the form and position of the horn and the scoop; yet on this

the performance of the machine greatly depends. The following instructions will render this tolerably easy. Let ABEO (fig. 3. pl. XVII.) represent the first or outermost spire, of which the axis is C. Suppose the machine immerged up to the axis in the water whose surface is VV′: it has been seen that it is most effective when the surfaces KB and O*n* of the water columns are distant from each other the whole diameter BO of the spire. Let therefore the pipe be first conceived of equal caliber to the very mouth E*e*, which we suppose to be just about to dip into the water: the surface O*n* is kept there in opposition to the pressure of the water column BAO by the compressed air contained in the quadrant OE, and in the quadrant which lies behind EB: and this compression is supported by the columns behind, between this spire and the rising pipe. But the air in the outermost quadrant EB is in its natural state, because it as yet communicates with the external air. When, however, the mouth E*e* has come round to A, it will not have the water standing in it in the same manner, leaving the half space BEO filled with compressed air; for it took in and confined only what filled the quadrant BE. It is obvious, therefore, that the quadrant BE must be so shaped as to take in and confine a much greater quantity of air; so that when it has come to A, the space BEO may contain air sufficiently dense to support the column AO. But this is not enough: for when the wide mouth now at A*a*′ rises up to the top, the surface of the water in it rises also, because the part AO*oa*′ is more capacious than the part of uniform bore OE*eo* that succeeds it, and that cannot contain all the water which it previously held. Since then the water in the spire rises above A, it will press the water back from O*n* to some other position *m*′*n*′, and the pressing height of the water column will be diminished by this rising on the other side of O. Hence it will appear that the horn must begin to widen, not from B, but from A, and must occupy the whole semicircle ABE; while its capacity must be to the capacity of the opposite side of uniform bore as the sum of BO and the height of a column of water which balances the atmosphere to the height of that column: for then the air which filled it when of the common density will fill the uniform side BEO, when compressed so as to balance the vertical column BO. But even this is not sufficient; for it has not taken water enough. When it dipped into the cistern at E it carried air down with it, and the pressure of the water in the cistern caused that fluid to rise into it a little way; and some water must have come over at B from the other side, which was drawing narrower. When, therefore, the horn is in the position EOA it is not full of water: consequently, when it comes into the situation OAB it

cannot be full, nor can it balance the air on the opposite side. Hence some will come out at o, and rise up through the water. The horn must therefore extend at least from O to B, or occupy half the circumference; and it must contain at least twice as much water as would fill the side BEO. Nay, if it be much larger, there may be no disadvantage; because the surplus of air which it takes in at E will be discharged as the end E*e* of the horn rises from O to B, and it will leave the precise quantity that is wanted. The overplus water will be discharged as the horn comes round to dip again into the cistern.

We must also secure the proper quantity of water. When the machine is so much immersed as to be up to its axis in water, the capacity which thus secures the proper quantity of air will also take in the proper quantity of water. But it may be erected so as that the spirals shall not even reach the water: and in this case it will answer the purpose if a scoop or shovel be joined to the horn, and so formed as to take in at least as much water as will fill the horn. This is all that is wanted in the beginning of the motion along the spiral, and more than is necessary when the water has advanced to the succeeding spire: but the overplus is discharged in the way just mentioned. The scoop, it should be observed, must be very open on the side next the axis, that it may not confine the air as it enters the water; for this would hinder it from receiving enough of that fluid.

As an example we shall give the dimensions of a machine erected at Florence, whose performance corresponded extremely well with the theory. The spiral is formed on a cylinder of 10 feet diameter, and the diameter of the pipe is 6 inches. The smaller end of the horn is of the same diameter; it occupies $\frac{3}{4}$ of the circumference, and is 7·8 inches wide at the outer end: here it joins the scoop, which lifts as much water as fills the horn, which contains 4340 Swedish cubic inches, each = 1·577 English. The machine makes 6 revolutions in a minute, and raises 1354 pounds of water, or 22 cubic feet, 10 feet high in a minute. Thus it raises more than $\frac{10}{11}$ths of what the theory would lead us to expect, and yet it is not perfect; for the spiral is throughout of equal caliber, and is formed on a cylinder instead of a conoid.

In this machine the friction is so inconsiderable that it need not be mentioned: but the great excellency is, that whatever imperfections there may be in the arrangement of the air and water columns, it only affects the elegance of the execution, causing the water to make a few more turns in the spiral before it can mount to the required height; but it wastes no power, because the power employed is always in proportion to the sum

of the vertical columns of water in the rising side of the machine, and the altitude to which the water is raised by it is in the very same proportion. The machine should be made to move very slow, that the water be not always dragged up by the pipes, which would cause more to run over from each column, and diminish the pressure of the remainder. If the rising pipe be made wide, and thus room be made for the air to escape freely upwards through the water, it will rise to the height assigned; but if the pipe be narrow, so that the air cannot rise freely, it rises almost as slowly as the water; and by this circumstance the water mixed with the air is raised to a much greater height, and this with hardly any augmentation of the power. Thus it is that the great performance of the Florentine machine (which is almost triple what a man can do with the best constructed pump) is accounted for. Lastly, we may observe that the entrance into the rising pipe should be no wider than the last part of the spiral; and it would be advisable to divide it into four channels by a thin partition, and then to make the rising pipe very wide, and to put into it a number of slender rods, which would divide it into several slender channels that would serve completely to entangle the air among the water: this procedure will greatly increase the heights to which the heterogeneous column may be carried.

We earnestly recommend the application and improvement of this machine to practical engineers: the principles on which its theory depends are confessedly intricate; but when judiciously constructed it is very powerful and effective in its operations: on which accounts we are sorry that hitherto it has not, as far as we recollect, been described in more than two British works, the *Transactions of the Society of Arts*, for 1776, and the *Encyclopædia Britannica.*

11. Desaguliers describes, in the second volume of his Experimental Philosophy, a very simple contrivance to raise water, which is this: to one end of a rope is fixed a large bucket, having a valve at its bottom, opening upwards: to the other end is fastened a square frame, and the cord is made to pass over two pulleys, each of about 15 inches diameter (and fixed in a horizontal plane), in such manner that as the bucket descends the frame ascends with equal velocity, and *vice versa.* The frame is made to run freely upon four vertical iron guide-rods passing through holes at its four corners; and when the bucket is filled with water at the well, the frame stands at the horizontal plane to which the water is to be raised: when the bucket is full, a man steps upon the frame (his weight, together with that of the frame, exceeding the weight of the vessel and

its contained water): this gives an ascending motion to the bucket, and causes the valve in its bottom to close. When the bucket is raised to the proper height a hook fixed there catches into a hasp at the side of the bucket, turns it over, and causes it to empty its water into a trough which conveys it where it is required: at this time the man and the descending frame have arrived at a platform which prevents their further descent, where the man remains till he finds the bucket above is empty; when he steps from the frame, and runs up a flight of stairs to the place from which he descended: the bucket in the mean while, being somewhat heavier than the frame, descends to the water, and raises the frame to its original position. Thus the work is continued, the man being at rest during his descent, and labouring in the ascent.

Desaguliers employed in this kind of work a "*tavern drawer*," who weighed 160lbs. whom he desired to go up and down 40 steps of $6\frac{1}{2}$ inches each (in all about 22 feet) at the same rate he would go up and down all day. He went up and down twice in a minute: so that allowing the bucket with a quarter of a hogshead in it to weigh 140lbs. he is able to raise it up through 22 feet twice in a minute: this Desaguliers estimates as equivalent to a whole hogshead raised 11 feet in a minute; and rather exceeds what he has assigned as a maximum of human exertion.

This machine is in many cases not only the most simple, but the best that can be devised; yet it is one that without due precautions is likely to be a very bad one. The frame on which the man steps must be brought up to its place again by preponderancy in the machine when unloaded: it should arrive precisely at the same time with the man; but it may arrive sooner or later. If sooner, it is of no use, and wastes power in raising a counterpoise which is needlessly heavy, or in fact less water is elevated than the man is able to elevate; if later, there is a loss of time. Hence the perfection of this truly simple machine requires the judicious combination of two maximums, each of which varies in a ratio compounded of two other ratios. It will not be difficult, however, to adjust the proportions of the weight of the bucket and that of the frame: for if B denote the weight of the bucket, F that of the frame, and ϕ the force necessary to overcome the friction and the inertia of the pulleys, g denoting $32\frac{1}{6}$ feet, t the time occupied in walking up the steps, and s the space ascended or descended, then must B and F be so adjusted as to satisfy the following equation, viz. $s = \frac{B-F}{B+F+\phi} \cdot \frac{1}{2}gt^2$.

12. If there be a spring affording but a small quantity of water, or having but a small fall, it is possible by the loss of some of the water to raise the rest to supply a gentleman's seat, or any place where it is wanted; but in a less quantity than what runs waste, if the place to which the water is to be raised is higher than the spring or reservoir from which the water falls. Schottus long ago contrived an engine for this purpose: but the first who put such a thing in execution was *Gironimo Finugio*, at Rome, in 1616; and the first in this country was *George Gerves*, a carpenter, who, in the year 1725, erected an engine called the Multiplying-wheel Bucket-engine, at the seat of Sir John Chester, at Chichley, in Buckinghamshire. This engine was much approved by Sir Isaac Newton, Dr. Desaguliers, and Mr. Beighton, and was certainly very ingenious. The water from a spring descended in a large bucket hanging by a cord from an axle, while a smaller quantity was raised from the same place by a cord hanging from a wheel on the same axle: a fly and other regulating apparatus were added, to make the engine work itself, which it did for many years without being out of order. As a whole, however, the contrivance is complex; and we are not aware that any other engines of the same kind have been erected. A description, with a plate, may be seen in Desaguliers's second volume.

Mr. *H. Sarjeant*, of Whitehaven, contrived a very cheap engine for raising water, for which the Society for the Encouragement of Arts awarded him a silver medal in the year 1801. A sketch of this simple invention is given in fig. 2. pl. XIX.

This engine was erected at Irton-hall, which is situated on an ascent of 60 or 61 feet perpendicular height: at the foot of this elevation, about 140 yards distant from the offices, there runs a small stream of water; and, in order to procure a constant supply of that necessary fluid, the object was to raise such stream to the house for culinary and domestic uses. With this view, a dam was formed at a short distance above the current, so as to cause a fall of about four feet: the water was then conducted through a wooden trough, into which a piece of leaden pipe, two inches in diameter, was inserted, and part of which is delineated at A.

The stream of this pipe is directed in such a manner as to run into the bucket B, when the latter is elevated; but, as soon as it begins to descend, the stream passes over it, and flows progressively to supply the wooden trough or well, at the foot of which stands the forcing-pump C, being three inches in diameter.

D is an iron cylinder attached to the pump-rod, which passes through it: such cylinder is filled with lead, and weighs about 240lbs. This power works the pump, and forces the water to ascend to the house through a pipe one inch in diameter, and which is 420 feet in length.

At E is fixed a cord, which, when the bucket approaches to within four or five inches of its lowest projection, extends, and opens a valve in the bottom of the vessel through which the water is discharged.

An engine in a great degree similar to this was erected some years ago by the late James Spedding, esq. for a lead mine near Keswick, with the addition of a smaller bucket which emptied itself into the larger near the beginning of its descent, without which addition it was found that the beam only acquired a libratory motion, without making a full and effective stroke.

To answer this purpose in a more simple way, Mr. Sarjeant constructed the small engine in such manner as to finish its stroke (speaking of the bucket-end) when the beam comes into a horizontal position, or a little below it. By this means the lever is virtually lengthened in its descent in the proportion of the radius to the cosine, of about thirty degrees, or as seven to six nearly, and consequently its power is increased in an equal proportion.

It is evident that the opening of the valve might have been effected, perhaps better, by a projecting pin at the bottom; but Mr. S. chose to give an exact description of the engine as it stands. It has now been some years in use, and completely answers the purpose intended.

The only artificers employed, except the plumber, were a country blacksmith and carpenter; and the whole cost, exclusive of the pump and pipes, did not amount to 5*l.*

In a letter, dated Whitehaven, April, 28, 1801, Mr. Sarjeant observes, that the pump requires about eighteen gallons of water in the bucket to raise the counter-weight, and make a fresh stroke in the pump; but it makes three strokes in a minute, and gives about half a gallon into the cistern at each stroke. He adds, "I speak of what it did in the driest part of last summer; when it supplied a large family, together with work-people, &c. with water for all purposes, in a situation where none was to be had before, except some bad water from a common pump which has been since removed. But the above supply being more than sufficient, the machine is occasionally stopped to prevent wear, which is done by merely casting off the string of the bucket valve."

13. Mr. *Benjamin Dearborn*, whose simple fire-engine has already been mentioned, has contrived a hydraulic engine

which may be conveniently added to a common pump, and thereby renders it useful in further elevating water, and particularly in extinguishing fires: the following description of his apparatus is extracted from the *Memoirs of the American Academy*.

Plate XIX. fig. 7. A, B, C, D, represents a pump, the form of which is similar to that of the pumps commonly employed on ship-board.

E, the spout.

F, a stopper.

D, *d*, a plank-cap, that is fitted to the pump, and provided with leather on its lower surface; being secured by the screws *a*, *b*: in the centre is a hole, through which the spear of the pump passes, and round which a leather collar is made, as represented at the letter *c*.

g, a nut for the screw *b*.

f, a square piece of wood that is nailed across one end of the plank-cap, through both which the screw *a* is introduced; a hole is made through such piece and the cap, that communicates with the bore of the pump.

G, G, a wooden tube which may be of any requisite length, and consist of any number of joints: it is made square at the lower extremity, and perforated for the reception of the cock; the upper end being made with a *nice* shoulder.

e, a wooden cock that opens or shuts the communication between the pump and the tube; being furnished on the opposite side with a handle and with a lock, in case it should be found necessary.

h, *h*, are two ferules, the object of which is to prevent the tube from splitting.

H, H, braces, each of which ought to be crossed over another as nearly at right angles as possible.

ii, are irons in form of a staple, which surround the tube, and pass through the braces; their ends being perforated with holes for fore-locks.

K, L, M, N, is a head made of five pieces of wood; *k*, *l*, *m*, *n*, a square piece, in the lower part of which is a hole for the reception of the extremity of the tube, and which piece rests on the shoulder *o*, *p*; to the lower end of this head is nailed a piece of leather, with a hole in its centre, similar to that made in the wood. Another piece of leather of the same form is placed on the top of the tube, and between both is a circle of thin plate-brass; the two pieces of leather and the brass being pressed between the lower end of the head and the shoulder of the tube. Their edges are delineated at *o*, *p*.

K, N, and L, M, are the edges of two pieces of plank, of a

similar width with the head, to which they are closely nailed; each being provided with a tenon, that passes through a mortice in the end of the piece O, P: both tenons have holes for a forelock at *q*.

O, P, a piece of plank of the same width as the sides; the centre of which is perforated, in order that the tube may pass through; and in each end of which is a mortice for the reception of the tenons.

N, M, a cap.

r, *r*, are two pieces nailed to the side of the tube; the lower extremity of each is provided with a truck, with a view to lessen the friction of the head in its horizontal revolution.

q, *q*, represent fore-locks, the design of which is to fasten down the head, and prevent the water from escaping at the joint *o*, *p*.

Q, R, is a wooden conductor; the extremity marked with the letter Q being solid, while the opposite end, R, is bored with a small auger.

s, a bolt that passes through the conductor and head, and being secured on the back with a fore-lock or nut: this bolt is rounded near the head, and square in the middle.

t, *u*, *w*, *x*, represents a piece of iron or brass, designed to prevent the head of the bolt from wearing into the wood.

S, S, are ropes for the direction of the conductor.

Fig. 8. represents the head without such conductor.

a, *b*, *c*, *d*, is a thick brass plate, the centre of which is perforated, so as to admit a passage to impurities, that might otherwise obstruct the conductor: for which purpose a piece of leather is nailed under it to the head. The square hole in the centre is adapted to the size of the bolt, which it prevents from turning. The conductor has a hollow cut round the bolt on the inside, of the same size as the circle of holes in the brass: round such cavity is nailed, on the face of the conductor, a piece of leather, that plays on the margin of the brass plate when the conductor is in motion.

In the conclusion of his Memoir, Mr. *Dearborn* observes, that he has raised a tube of 30 feet on his pump; and, though the severity of the season had prevented him from completing it, so that one person only could work at the brake, yet he is enabled to throw water on a contiguous building, the nearest part of which is 37 feet from the pump, and between 30 and 40 feet in height.

14. The *Hydraulic Ram*, invented by M. Joseph Montgolfier, is a machine the construction of which is founded upon the acceleration of the velocity of a liquid mass falling in a tube, and the communication of that motion to another liquid mass

moving with a less velocity than the former. We know that a heavy body falling in vacuo runs over $16\frac{1}{12}$ feet in the first second; and a liquid column which falls in an unresisting vertical tube passes over the same space in the same time, with a motion uniformly accelerated: supposing this tube kept constantly full, and considering the friction of the particles of the fluid against one another, and against the sides of the tube, the motion is such, that, though it ceases to be uniformly accelerated, the velocity of the column, at first nothing, arrives by degrees at its maximum, in a longer or shorter time, depending on the dimensions and form of the tube; the contained fluid having acquired a certain velocity, there results a certain quantity of motion; the object of the hydraulic ram is to communicate a part of this motion to the mass of water which is to be elevated.

To understand the construction of this machine, suppose that an orifice is made through the pier or embankment of a reservoir of either standing or running water, at the depth of 4 or 5 feet below the surface of the fluid, such orifice receiving one end of a cylindrical tube about 20 or 24 feet long, the tube being formed of iron, copper, or other suitable materials, and placed horizontally, and firmly supported through its whole length by timber or by masonry. To the end of this tube farthest from the reservoir is adapted a piece of iron or of copper, called *the head of the ram;* it has two orifices, both of which open horizontally; the sucker of one of these closes by ascending, that belonging to the other closes by descending: these valves are guided in their motions by rings which traverse the handles attached to their centres. The orifice which has the ascending valve, and which is in fact the remoter orifice, permits the water to escape freely: the other is covered by a kind of tower, which serves as an air-vessel, and is pierced on one side by a hole to which a tube is adapted that is elevated to the height to which it is proposed to raise the water. See also 1D, pl. XXXVIII.

To understand the *action* of the machine, let it be considered that when the remoter orifice is open, the water which runs along the horizontal tube will escape with a velocity which will continue to increase until the impression of the stream raises the valve and closes the orifice: hence the motion of all the water in the tube is suddenly stopped, and the *vis viva* acquired exerts itself on all parts of the tube, and consequently on the rising valve, which giving way permits the water to escape through it into the vessel above: the force existing in the cylinder being thus employed, the pressure to which the valve yielded becomes annihilated, and the sucker redescends, closing

its orifice: the velocity of the water in the horizontal tube being thus destroyed, the remoter orifice again permits the water to escape through it, and the same operations are repeated so long as there is a proper supply of water. Thus it will be seen that every time the valve closes the remoter orifice, a portion of the moving water passes into the air-vessel above the other valve; there will soon be a sufficient quantity to cover the inferior extremity of the ascending tube, and then the air which is above the water in the air-vessel, having no communication with the atmosphere, will be compressed if the machine continue to act, and its expansive force increasing with the compression, will compel the water to move up the ascending pipe; though always in a quantity inversely proportional to the altitude to which it is to be raised.

Every time the remoter or discharging sucker shuts, a report is heard similar to that of the stroke of a hammer, and which furnishes a mean of knowing how often it is closed in a given time.

We have only spoken of one kind of ram; but the same principles are susceptible of a very extensive application: thus, it would be easy to raise other water besides that which runs through the ram; as, for example, with a fall of water, we might by a slight modification of this machine raise water from the bottom of wells or of mines.

To judge of the merit of a hydraulic machine we must consider its produce, the expense of its erection, and that of keeping it in repair. Now in every hydraulic machine the force expended is the product of the water which comes from its source multiplied by the height it falls through before it acts on the machine; the produce being the product of the quantity of water raised in the same time, multiplied by the height to which it is elevated. Now, in an experiment made upon the ram erected at the Polytechnic School, it appeared that the expense was to the produce as 100 : 45. For, the height of the fall is 1 metre 82, that of the ascending pipe 11 m. 66, the tube of the vertical or active column ·054 m. in diameter, being fixed at the bottom of an oval-shaped vessel; the horizontal or passive column, also ·054 m. in diam.; the ascending tube of tin ·002 m. interior diam. and 11 m. 66 elevation; the total length 32 m. 66. The discharging valve closed from 40 to 42 times in a minute. The water which fell in 10 minutes was 493·7 litres; that which was raised up the ascending tube in the same time 51·8; from which data flows the ratio just stated.

In another hydraulic ram placed in M. Montgolfier's garden (Rue des Juifs, No. 122), the fall which was procured artificially was $7\frac{1}{2}$ feet; the height to which the water was raised,

50 feet; the diameter of the tubes 2 inches; the water expended in 4 minutes was 315 litres, that elevated 30 litres; hence the expense or force employed is $7\frac{1}{2} \times 315 = 2362$; the useful force $50 \times 30 = 1500$; and these are in the ratio of 100 : 64.

In an experiment made upon a ram at Avilly, near Senlis, by M. Turquet, bleacher, the expense was found to be to the produce as 100 : 62. In an experiment on a fourth machine, in which the passive column was 10 m. 4 in length, and the height of the ascending pipe nearly 7 times that of the head of water, the discharging valve closed 104 times in a minute, and the expense was to the produce as 100 : 57. Taking the mean of these experiments, the expense will be to the produce as 100: 57, so that a hydraulic ram placed not in unfavourable circumstances, and executed with care, may be said to employ usefully at least half its force.

One of our most simple engines for purposes similar to those in which the *ram* could be applied is Sarjeant's bucket engine (see No. 12 of the present article), in which the expense is to the produce nearly as 100 to 42, a ratio not much inferior to that of the ram at the Polytechnic School. But the machine most analogous to M. Montgolfier's in principle, next to that by Mr. Boulton, is the hydraulic engine at Chemnitz: in which the expense is 66 feet of water falling 136 feet, in the same time that the produce or performance is 32 feet raised 96; they are therefore in the proportion of 66×136 to 32×96, or nearly as 100: 34. Even this is superior to the performance of the most perfect undershot mill, and might certainly be considerably increased, by giving more favourable proportions to the feeding and discharging pipe than in the existing machine. And if, in addition to this, the ingenious apparatus of Mr. Boswell, enabling the machine to work itself, be appropriated skilfully to such a general contrivance, it will doubtless be as favourable as the hydraulic ram. M. Montgolfier suggests the utility of his invention in the draining of mines: and in that case, the hydraulic ram, and the Hungarian machine, would become nearly, if not altogether, identical as to the principle.

15. The *Danaide*, a new hydraulic machine, invented by M. Mannoury Dectot, is thus described by MM. Perier, Prony, and Carnot, in their Report to the French Institute.

The model by which this mechanist exhibited his experiments consists principally of a trough, the bottom of which has a hole in its centre: it is cylindrical, nearly as high as it is broad, and made of tin-plate. It is fixed to a vertical axis of iron, which passes through the middle of the hole in the bottom, leaving a vacant space all round, through which water escapes as it flows

into the trough (from above): this axis turns, with the trough upon a pivot, and is fixed above to a collar.

The object of the inventor was that the water flowing into the trough from above, with a certain quantity of *vis vivæ*, should communicate the whole of it to the solid parts of the machine, so as to be employed afterwards in producing some useful effect; always excepting the small quantity of force necessary to enable the water to escape by the orifice below. This object he thus obtains.

Within the trough there is affixed to the axis a drum, likewise of tin-plate, concentric with the trough, and close above and below. This drum, which turns round with the trough, occupies nearly the whole of its capacity; the space between the two not exceeding an inch and a half. A similar space exists also between the bottom of the trough and the drum; it is however less than the former, and is divided into several compartments by diaphragms proceeding from the circumference to the central hole in the bottom of the trough. These diaphragms do not exist between the sides of the drum and the trough, and the compartments at the bottom communicate with this annular space.

The water, which comes from a reservoir above by one or two pipes, makes its way into this annular space between the drum and the trough. The bottoms of these pipes correspond with the level of the water in the trough, and they are directed horizontally, as tangents to the mean circumference between that of the trough and of the drum. The force which the water has acquired by its fall along the pipes causes the machine to move round its axis; and this motion gradually accelerates till the velocity of the water in the space between the trough and the drum equals that of the water from the reservoir: so that the shock of the water from above upon that of the machine becomes imperceptible.

Now this circular motion communicates to the water between the trough and the drum a centrifugal force, in consequence of which it presses against the sides of the trough. The centrifugal force acts equally upon the water contained in the compartments at the bottom of the trough, but obviously less and less as the water approaches the centre. The whole water, then, is actuated by two forces which oppose each other; namely, gravity and the centrifugal force. The first tends to make the water run out at the orifice at the bottom of the trough; the second tends to drive the water from that hole. To these two forces are joined a third, namely, *friction*, which here acts an important and singular part, since it promotes the efficacy of the machine, while in other machines it always diminishes that

efficacy. Here, on the contrary, the effect would be nothing were it not for the friction, which acts in a tangent to the sides of the trough and drum.

By the combination of these three forces there must result a more or less rapid flow from the orifice at the bottom of the trough; and the less force the water has as it escapes, the more it will have employed in moving the machine, and consequently in producing the useful effect for which it is destined.

The moving power is the weight of the water running in, multiplied by the height of the reservoir from which it flows above the bottom of the trough: and the useful effect is the same product diminished by half the force which the water retains when it issues from the orifice below.

The Reporters endeavoured to ascertain by direct experiment the amount of this useful effect. They fixed a cord to the axis of the machine, which, by means of pulleys properly placed, raised a weight as the machine turned round. The result of repeated experiments was, that the effect produced amounted to $\frac{7}{10}$ and sometimes to $\frac{75}{100}$ of the moving cause; an effect which surpasses that of the best machines known.

16. HARRIOT'S ENGINE, for Raising and Lowering Weights, &c. by the Action of a Column of Water.

A A, in fig. 1 and 2, pl. XLIII. is a cylinder with a moving piston therein, of which D is the piston rod.

B and C are water ways, through which the water is admitted to communicate with both sides of the piston.

E F, a pipe in fig. 1, through which water descends from a reservoir above, into a three-way cock M, and in fig. 2 is a pipe through which any stream or head of water runs to the three-way valve in the cistern M.

C H is a pipe in both, communicating from the three-way cock, or valve, to the upper part of the cylinder.

K B is a pipe communicating from the same cock, or valve, to the lower part of the cylinder.

I I is a pipe, communicating between the two last mentioned pipes, consequently between the upper and lower spaces of the cylinder, which communication can be either cut off or opened to any requisite degree by the cock L.

N is a pipe in which a lower column of water is suspended by the reaction of the atmosphere, and consequently a power to the upper column or fall, in proportion to its length or depth, not exceeding the weight of the atmosphere.

Remarks.—The nature and principle of the syphon engine consists in combining the power of the syphon with the direct pressure of a column or stream of water, so that they may act together. It works by means of the syphon constantly acting

in concert with the feeding stream of water, so that each alternately acts on the upper and lower part of a piston, within a cylinder as it were, reversing the syphon at each change; and the power is equal to a column of water of the same diameter as that of the cylinder, and equal in length to the height of the head, above the tail water. For instance, if a column of water of any given diameter has a fall of 20 feet until it reaches an engine, its power is clearly ascertained. Now, whatever that power is, if a syphon pipe be added to this engine, so as to connect with the column, and the syphon pipe has also a fall of an equal length, namely, 20 feet to the lower end, which is immersed in water, the engine, although placed in the midway, will then have a power equal to that of a descending column of 40 feet; and should the column or fall to the engine be but 2 feet, and the lower syphon pipe 24 feet, the power would be equal to a fall of 26 feet; and in this manner in various diversity between the falling column and the syphon pipe beneath, the latter will produce an equal power according to its proportionate length, or depth, to the surface of the tail water, provided it does not exceed above 30 feet, or the weight of the atmosphere; and where a stream of water is either level with, or even below, the place at which it is desirable to fix the engine, there will be no difficulty in placing it either below, or on the level, or above the stream itself, provided the height it is fixed above does not exceed 28 or 30 feet, and the place where the water flows off be still lower. The construction may evidently be varied according to the local situation and circumstances of applying it, and the use to which it may be adapted, in giving activity to different kinds of machinery.

The drawing, fig. 1, exhibits the apparatus for raising or lowering weights of any kind, on wharfs or in warehouses. A man or boy can raise or lower goods of any weight, without other exertion than that of merely turning the three-way cock M to an index; in either raising or lowering, the *stop* is instantaneous, by a small motion, or turning the cock to the stop mark in the index; this most effectual of stops, or gripe, operates so quietly and easily without any jerk or jarring, that it removes the usual risk attending common cranes or machinery, in which men are sometimes overpowered. It raises and lowers goods with thrice the velocity usually produced by manual labour; yet an engine of dimensions sufficient to raise several tons may be so graduated by the person at the cock, as to bring it to the smoothest slowest motion possible. The saving of labour and time must therefore be considerable, the risk of plunder diminished, and delays in setting to work for want of help removed.

The great obstacle to the use of the syphon engine, and this

was stated by its inventor, is the want of a head of water in most places where the engine could be used to greatest advantage; but so conscious was he of the advantages of his invention for raising goods to warehouses and granaries, that he proposed raising water by other means into a reservoir at the top of the warehouse, to be used afterwards in raising the goods. This obstacle appears hitherto to have prevented any attempt to put Mr. Harriot's engine to any practical use; but in Glasgow, where water is raised to the top of the very highest house in the city, we think the syphon engine might be used for many useful purposes, and might save a great deal of human labour. It might be used very advantageously at the Broomielaw, for raising and lowering goods from and to the vessels, when they are loading and unloading.

The drawing, fig. 2, shows how the syphon engine is to be applied to streams of water; the advantages of which are, that the engine, as well as the mill work, or manufacturing machinery it may drive, may be placed where most convenient, above or below the head or stream, to be worked by a fall of water from the least to the greatest height, or by any stream or river, the tail water below acting and having as much power as the head, answering to the height of either.—(*Glasgow Mech. Mag.*)

HYDROMETERS. See vol. I. arts. 401, 409.

HYGROMETER, or HYGROSCOPE, or NOTIOMETER, an instrument contrived to measure the humidity of the air.

The instruments hitherto invented for this purpose have not been attended with that accuracy which there was reason to expect and to hope for. We have hygrometers, it is true, which indicate that the air has been more or less moist; but they have often this fault, that they indicate a greater degree of moisture than really exists in the atmosphere: besides, they are not comparable; that is to say, it is not possible by their means to compare the moisture of one day, or of one place, with that of another. It may not, however, be improper to describe a few of the contrivances of this kind, if it be only that their utility may be examined.

1. As fir wood is very susceptible of participating in the dryness and moisture of the atmosphere, some have conceived the idea of applying this property to the construction of an hygrometer. For this purpose, a small, very thin fir board, is placed across between two vertical immoveable pillars, so that the fibres stand in a horizontal direction; for it is in the lateral direction, or that transversal to its fibres, that fir and other kinds of wood are extended by moisture. The upper edge of the board ought to have a small rack, fitted into a pinion, connected with a wheel, and the latter with another wheel, having on its axis an

index. It may be easily perceived, that by these means the least motion communicated by the upper edge of the board to the rack, by its rising or falling, will be indicated in a very sensible manner by the index; consequently, if the motion of the index be regulated in such a manner, that from extreme dryness to extreme moisture it may make a complete revolution, the divisions of this circle will indicate how much the present state of the atmosphere is distant from either of these extremes.

This invention is ingenious, but it is not sufficient. The wood retains its moisture a long time after the air has lost that with which it was charged; besides, the board gradually becomes less sensible to the impressions of the air, and therefore produces little or no effect.

2. Suspend a small circular plate by a fine string, or piece of catgut, fastened to its centre of gravity, and let the other end of the string be attached to a hook. According as the air is more or less moist, you will see the small plate turn round in one direction or in another.

The hygrometers commonly sold are constructed on this principle. They consist of a kind of box, the fore part of which represents a building with two doors. On one side of the metal plate which turns round, stands the figure of a man with an umbrella, to defend him from the rain, and on the other a woman with a fan. The appearance of the former of these figures indicates damp, and that of the other dry weather. This pretended hygrometer can serve for no other purpose than to amuse children; for the philosopher must observe that, as the variations of humidity are transmitted to this instrument only by degrees, it will indicate moisture or drought when the state of the atmosphere is quite contrary.

3. Some have tried to construct an hygrometer, by making fast a piece of catgut at one extremity, winding it backwards and forwards over different pulleys, and suspending from its other extremity a small weight, behind which is placed a graduated scale. Others dispose the extremity of the catgut in such a manner, as to cause it to move an index round a graduated plate, the different degrees of which indicate the dryness or moisture of the atmosphere. This instrument, however, is subject to the same inconveniences as that before mentioned.

4. Put into one scale of a balance any salt that attracts the moisture of the air, and into the other a weight, in exact equilibrium with it. The scale containing the salt will sink down during damp weather, and thereby indicate that such is the state of the atmosphere. An index, to determine the different degrees of drought or moisture, may be easily adapted to it.

This instrument however is worse than any of the rest; for a salt immersed in moist air becomes charged with a great deal of humidity, but loses it very slowly when the air becomes dry: fixed alkali of tartar even imbibes moisture till it falls *in deliquium*, that is to say, till it is reduced to a liquid or fluid state.

5. Music may be employed to indicate the dryness or moisture of the air. The sound of a flute is higher during dry than during moist weather, and the string of a violin exhibits the same phenomenon; but neither of these can show the immediate state of the air in regard to dryness or humidity.

6. M. De Luc's contrivance for an hygrometer is on this principle. Finding that even ivory swells with moisture, and contracts with dryness, he made a small and very thin hollow cylinder of ivory, open only at the upper end, into which is fitted the under or open end of a very fine long glass tube, like that of a thermometer. Into these is introduced some quicksilver, filling the ivory cylinder, and a small part of the length up the glass tube. The consequence is this: when moisture swells the ivory cylinder, its bore or capacity grows larger, and consequently the mercury sinks in the fine glass tube; and, *vice versa*, when the air is drier, the ivory contracts, and forces the mercury higher up the tube of glass. It is evident that an instrument thus constructed is in fact also a thermometer, and must necessarily be affected by the vicissitudes of heat and cold, as well as by those of dryness and moisture; or that it must act as a thermometer as well as an hygrometer. The contrivances in the structure and mounting of this instrument are described in the Philos. Trans. vol. 63, art. 38; where it may be seen how the above imperfection is corrected by some simple and ingenious expedients, employed in the original construction and subsequent use of the instrument; in consequence of which, the variations in the temperature of the air, though they produce their full effects on the instrument as a thermometer, do not interfere with or embarrass its indications as an hygrometer.

7. In the Philos. Trans. for 1791, M. De Luc has given a second paper on hygrometry. This has been chiefly occasioned by a Memoir of M. De Saussure on the same subject, entitled Essais sur l'Hygrometrie, in 4to, 1783. In this work M. De S. describes a new hygrometer of his construction, on the following principle. It is a known fact, that a hair will stretch when it is moistened, and contract when dried: and M. De Saussure found, by repeated experiments, that the difference between the greatest extension and contraction, when the hair is properly prepared, and has a weight of about 3 grains suspended

by it, is nearly one 40th of its whole length, or one inch in 40. This circumstance suggested the idea of a new hygrometer. To render these small variations of the length of the hair perceptible, an apparatus was contrived, in which one of the extremities of the hair is fixed, and the other, bearing the counterpoise above mentioned, surrounds the circumference of a cylinder, which turns upon an axis to which a hand is adapted, marking upon a dial in large divisions the almost insensible motion of this axis. About 12 inches high is recommended as the most convenient and useful: and to render them portable, a contrivance is added, by which the hand and the counterpoise can be occasionally fixed.

But M. De Luc, in his Idées sur la Meteorologie, vol. i. anno 1786, shows that hairs, and all the other animal or vegetable hygroscopic substances, taken lengthwise, or in the direction of their fibres, undergo contrary changes from different variations of humidity; that when immersed in water, they lengthen at first, and afterwards shorten; that when they are near the greatest degree of humidity, if the moisture be increased, they shorten themselves; if it be diminished, they lengthen themselves first before they contract again. These irregularities, which render them incapable of being true measures of humidity, he shows to be the necessary consequence of their organic reticular structure. De Saussure takes his point of extreme moisture from the vapours of water under a glass bell, keeping the sides of the bell continually moistened; and affirms, that the humidity is there constantly the same in all temperatures; the vapours even of boiling water having no other effect than those of cold. De Luc, on the contrary, shows that the differences in humidity under the bell are very great, though De Saussure's hygrometer was not capable of discovering them; and that the real undecomposed vapour of boiling water has the directly opposite effect to that of cold, the effect of extreme dryness: and on this point he mentions an interesting fact, communicated to him by Mr. Watt, viz. that wood cannot be employed in the steam-engine for any of those parts where the vapour of the boiling water is confined, because it dries so as to crack as if exposed to the fire.

To these charges of M. De Luc, a reply is made by M. De Saussure, in his Defence of the Hair Hygrometer, in 1788; where he attributes the general disagreement between the two instruments to irregularities of M. De Luc's; and assigns some aberrations of his own hygrometer, which could not have proceeded from the above cause, but to its having been out of order, &c.

This has drawn from M. De Luc a second paper on hygro-

metry, published in the Philos. Trans. for 1791, p. I. and 389. This author here resumes the four fundamental principles which he had sketched out in the former paper, viz. 1st, That fire is a sure, and the only sure, means of obtaining extreme dryness. 2d, That water, in its liquid state, is a sure, and the only sure, means of determining the point of extreme moisture. 3d, There is no reason, *à priori*, to expect from any hygroscopic substance, that the measurable effects produced in it by moisture are proportional to the intensities of that cause. But 4th, perhaps the comparative changes of the dimensions of a substance, and of the weight of the same or other substances, by the same variations of moisture, may lead to some discovery in that respect. On these heads M. De Luc expatiates at large in this paper, showing the imperfections of M. De Saussure's principles of hygrometry, and particularly as to a hair, or any such substance when extended lengthwise, being properly used as an hygrometer. On the other hand, he shows that the expansion of substances across the fibres, or grain, renders them, in that respect, by far the most proper for this purpose. He chooses such as can be made very thin, as ivory or deal shavings, but he prefers whalebone, as far the best.

The preceding general description of the principal hygrometers will, we trust, be sufficient to show that great imperfection and uncertainty attends the use of any of them; and, at the same time, to justify us in not entering more into detail respecting the construction of these instruments.

JACK, an instrument in common use for raising heavy timber, or very great weights of any kind; being a powerful combination of teeth and pinions, and the whole inclosed in a strong wooden stock or frame BC, and moved by a winch or handle HP; the outside appearing as in fig. 5. pl. VIII. In fig. 6. the wheel or rack work is shown, being the view of the inside when the stock is removed. Though it is not drawn in the just proportions and dimensions, for the rack A B must be supposed at least four times as long in proportion to the wheel Q as the figure represents it; and the teeth, which will be then four times more in number, to have about 3 in the inch. Now if the handle HP be 7 inches long, the circumference of this radius will be 44 inches, which is the distance or space the power moves through in one revolution of the handle: but as the pinion of the handle has but four leaves, and the wheel Q suppose 20 teeth, or 5 times the number, therefore to make one revolution of the wheel Q, it requires 5 turns of the handle, in which case it passes through 5 times 44 or 220 inches: but the wheel having a pinion R of 3 leaves, these will raise the rack 3 teeth, or one inch, in the same space. Hence, then, the handle or power moving 220

times as fast as the weight, will raise or balance a weight of 220 times its own energy. And if this be the hand of a man who can sustain 50 pounds weight, he will, by help of this jack, be able to raise, or sustain, a weight or force of 11,000 lb. or about 5 tons weight.

This machine is sometimes open behind from the bottom almost up to the wheel Q, to let the lower claw, which in that case is turned up as at B, draw up any weight. When the weight is drawn or pushed sufficiently high, it is kept from going back by hanging the end of the hook S, fixed to a staple, over the curved part of the handle at *h*.

The Society of Arts rewarded a Mr. Mocock, of Southwark, with a premium of 20 guineas, for his contrivance to prevent a jack from taking a retrograde course whenever the weight by any accidental circumstance overbalances the power. The improved jack only differs from those in common use in this respect, that it has a pall or clock, and ratchet, applied in such manner as to stop the motion of the machine as soon as it begins to run back again. As the difference in the mechanism is very trifling, the improvement may be easily applied to any common jacks already made.

JACK is also the name of a well-known engine in the kitchen, used for turning a spit. Here the weight is the power applied, acting by a set of pulleys; the friction of the parts, and the weight with which the spit is charged, are the forces to be overcome; and a steady uniform motion is maintained by means of a fly.

The common worm-jack is represented at fig. 2. pl. XII. ABC is the barrel round which the cord QR is wound: KL the main wheel, commonly containing 60 teeth. N the worm wheel of about 30 teeth, cut obliquely. LM the pinion, of about 15. O the worm or endless screw, consisting of two spiral threads, making an angle of 60 or 70 degrees with its axis. X the stud, and Z the loop of the worm spindle. P a heavy wheel, or fly, connected with the spindle of the endless screw, to make the motion uniform. DG the struck wheel fixed to the axis FD. S, S, S, are holes in the frame, by which it may be nailed to a board, and thence to any wall, the end D being permitted to pass through it. HI the handle going upon the axis ET, to wind up the weight when it has run down. R is a box of fixed pulleys, and V a corresponding one of moveable pulleys carrying the weight. The axis ET is fixed in the barrel AC, which axis being hollow, both it and the barrel turn round upon the axis FD, which is fixed to the wheel KL, when it turns in the order BTA; but cannot turn the contrary way, by reason

of a catch nailed to the end AB, which lays hold of the cross-bars in the wheel LK.

The weight, by means of the cord QR, in consequence of its descent, carries about the barrel AB, which by the action of the catch carries the wheel KL, and this moves the pinion LM and wheel N, the latter moving the worm O and the fly P. Also the wheel LM carries the axis FD with the wheel DG, which carries the cord or chain that goes about the wheel or pulley at the head of the spit. But when the handle H gives motion to the axis in a contrary direction to that given by the weight, the catch is depressed; so that although the barrel BC moves and winds the cord upon it, the wheel DG continues at rest. The time which the jack will continue in motion depends upon the number of pulleys at R and V: and as these increase or decrease, so must the weight which communicates the motion, in order to perform the same work in the same time.

SMOKE-JACK is an engine used for the same purpose as the common jack; and is so called from its being moved by means of the smoke, or rarefied air, ascending the chimney, and striking against the sails of the horizontal wheel AB (plate XII. fig. 1.), which being inclined to the horizon, is moved about the axis of the wheel, together with the pinion C, which carries the wheels D and E; and E carries the chain F, which turns the spit. The wheel AB should be placed in the narrow part of the chimney, where the motion of the smoke is swiftest, and where also the greatest part of it must strike upon the sails.—The force of this machine depends upon the draught of the chimney, and the strength of the fire.

Smoke-jacks are sometimes moved by means of spiral flyers coiling about a vertical axle; and at other times by a vertical wheel with sails like the float-boards of a mill: but the above is the more customary construction.

JOINT, UNIVERSAL. See the introductory part of this volume.

KNEADING-MILL, is a contrivance by which large quantities of flour may be mixed and incorporated into dough.

In many places bakers follow the disgusting practice of kneading the dough with their bare feet: and in others the business is effected by a wooden implement, being a lever; which, fastened at one end by a moveable hinge, is worked up and down so as to press and knead the dough. But the machine we are about to describe is far preferable, as it will knead the dough very completely, with a great saving of time and labour. It is used at the public baking-houses of Genoa, and

was first described in the *Atti della Societa Patriotica di Milano,* vol. II.

A, in fig. 4. pl. XVIII. is a frame of wood which supports the axis of the machine: a wall 14 palms high from the ground may be made use of instead of this frame. B, a wall three palms and a half thick, through which the aforesaid axis passes. C another wall similar to the former, and facing it, at the distance of 21 palms. D, the axis, thirty palms in length, and one palm and one-third in thickness. E, the great wheel, fixed to the said axis, between the frame and the wall; its diameter is 28 palms; and its breadth, which is capable of holding two men occasionally, is five palms. F, are steps, by treading on which the men turn the wheel very smartly; they are two palms distant from each other, and one-third of a palm in height. G, a small wheel with cogs, fixed almost at the further extremity of the axis: its diameter is $12\frac{1}{2}$ palms. H, a beam of wood which extends from one wall to the other; being 21 palms in length, and one and a third in thickness. A similar beam, not seen in the figure, is on the opposite side of the axis. I, a transverse piece of wood, placed near the wall C: it is fixed into the two beams, and serves to support the further extremity of the axis: its length is 14 palms, and its thickness one and a third: there is likewise a transverse piece (which cannot be seen in the figure) 14 palms long, and half a palm thick, placed close to the wall B. K is a strong curved piece of oak, fixed transversely in the sidebeams H, to receive the axis of the trundle: its length is 14 palms, and its thickness $1\frac{1}{3}$. L is a trundle of $5\frac{1}{2}$ palms in diameter, and $1\frac{1}{4}$ in height, which is moved by the cogged wheel G. M is an axis proceeding from the trundle, L, and continued through the cross N to the bottom of the tub P; its centre is made of iron, partly square and partly round, and it turns in a socket of brass. The first part of this axis between the trundle L and the cross N is of square iron, surrounded by two pieces of wood, held together by iron hoops, which may be removed at pleasure to examine the iron within; its length is three palms, its diameter about 1 palm. The second part of the axis which is within the tube is made like the first part: its height is $1\frac{1}{2}$ palm, its diameter $1\frac{1}{6}$. The wooden sheath of this part of the axis is fixed to the bottom of the tub, by means of three screws with their nuts. This axis is distant one-third of a palm from the nearest triangular *beater* of the cross. N, the cross, formed of two bars of wood unequally divided, so that the four arms of the cross are of different lengths: one of the two pieces of wood of which the cross is made is 6 palms in length, the other 5: their thickness is $\frac{7}{12}$ of a palm, and their breadth 1 palm. O, four pieces of wood, called

beaters, of a triangular shape, fixed vertically into the extremities of, and underneath, the arms of the fore-mentioned cross: they are $1\frac{3}{4}$ palms in length, and half a palm in thickness; and beat or knead the dough in the tub at unequal distances from the centre. P is a stout wooden tub, about a quarter of a palm thick, well hooped with iron: its diameter is 6 palms, its height $1\frac{1}{2}$ in the clear.

Fig. 5. is a box or trough of wood, 4 palms long, and 3 wide, in which the leaven is formed (in about an hour) in a stove, and in which it is afterwards carried to the tub P.

Fig. 6. exhibits a view of the trundle, cross, &c. with a section of the tub.

Fig. 7. is a bird's-eye view of the cross and tub, with the upper ends of the triangular beaters.

This tub, P, will contain 18 rubbi (about 19 bushels) of flour, which is carried to it in barrels: the leaven is then carried to it in the box or trough, fig. 5. and when the whole is tempered with a proper quantity of warm water, the men work in the wheel till the dough is properly and completely kneaded. In general a quarter of an hour is sufficient to make very good dough; but an experienced baker who superintends, determines that the operation shall be continued a few minutes, more or less, according to circumstances.

The measures in the preceding description are given in Genoese palms, each of which is very nearly equal to 9·85 of our inches. The machinery may be varied in its construction according to circumstances, and the energy of the first mover much better applied than by men walking in a common wheel.

LATHE, a very useful engine for the turning of wood, ivory, metals, and other materials. The invention of the lathe is very ancient: Diodorus Siculus says, the first who used it was a grandson of Dædalus, named Talus. Pliny ascribes it to Theodore of Samos; and mentions one Thericles, who rendered himself very famous by his dexterity in managing the lathe. With this instrument the ancients turned all kinds of vases, many whereof they enriched with figures and ornaments in basso relievo. Thus Virgil: "*Lenta quibus torno facili superaddita vitis.*"

The Greek and Latin authors make frequent mention of the lathe; and Cicero calls the workmen who used it *vascularii*. It was a proverb among the ancients, to say a thing was formed in the lathe, to express its delicacy and justness.

The common lathe is composed of two wooden cheeks or sides, parallel to the horizon, having a groove or opening between: perpendicular to these are two other pieces called *puppets*,

made to slide between the cheeks, and to be fixed down at any point at pleasure. These have two points, between which the piece to be turned is sustained: the piece is turned round backwards and forwards by means of a string put round it, and fastened above to the end of a pliable pole, and underneath to a tredle or board moved with the foot. There is also a rest which bears up the tool, and keeps it steady. But the most ingenious lathes now constructed are different from the above: we shall describe them under the article TURNING.

LENS GRINDING MACHINES, have been invented of many different kinds; but, since it has been admitted that, on the whole, spherical lenses are the most practically useful, the construction of lens-grinders has become comparatively simple. One of the best we have seen was invented by Mr. *Sam. Jenkins*, and described in No. 459. vol. xli. of the *Phil. Transac.* It is contrived to turn a sphere at one and the same time on two axes, cutting each other at right angles, and will produce the segment of a true sphere merely by turning round the wheels, without any care or skill of the workmen. A (fig. 1. pl. XX.) is a globe covered with cement, in which are fixed the pieces of glass to be ground: this globe is fastened to the axis, and turns with the wheel B. C is the brass cup which polishes the glass: this is fastened to the axis, and turns with the wheel D. The motion of the cup C, therefore, is at right angles to the motion of the globe A; whence it follows, demonstrably, that the pieces of glass ground by this double motion must be formed into the segments of spheres.

THE LEVER, treated as one of the mechanical powers, fell under our notice in book I. ch. iii. vol. I. where the theory of the various kinds of levers, whether straight or bent, was laid down. Our present object is to describe a combination of the lever with the axis in peritrochio, by means of which the reciprocating motion of the lever is made useful in giving a continued rectilinear motion to a heavy body, without changing the situation of the fulcrum of the lever. This contrivance is described by Belidor (Archit. Hydraul. tom. I.) under the name of *le levier de la Garousse*, and is generally called in England the *universal lever*. FGH (fig. 2. pl. XX.) is a straight lever, whose centre of motion is G: on its extremity F, hang two bars FD, FE, the former of which has a hook to catch into the teeth of the wheel ACD, and the latter has its end slightly bent, so as to slide over the outer parts of those teeth. The axle A has a cord wound about it, to the lower end of which is attached the weight W. Now suppose the end H of the lever raised from H by I, while the other end descends from F to B; the bar FE will then push the point E of the wheel from E to C,

while the hook D slides over an equal space on the other side of the wheel. After this, on the end H of the lever being brought down again by I to H, the end F ascends through BF, and the hook D raises up the left hand side of the wheel through a space equal to EC. Thus the reciprocating motion of the lever is made to communicate a continued rotatory motion to the wheel, and consequently to raise the weight W suspended from its axle by the cord. Here the advantage gained, neglecting friction and the stiffness of the cord, will be in the ratio compounded of the ratio of HG to GF, and the ratio of the radius of the wheel to that of the axle. Thus if HG were ten times GF, and the radius of the wheel 10 times that of the axle, the power would then be to the weight raised nearly as 1 to 100.

This machine has been advantageously applied in drawing heavy loads along a plane nearly horizontal: in that case, the cord has been carried from A in nearly a horizontal direction, passed round a pulley *p*, attached to the load *w* or its carriage, and its end fixed to a post as at *a*, or perhaps to the frame of the wheel and axle. The pulley, it is obvious, almost doubles the advantage of the power; and since the force to be overcome when once the system is put in motion is not equivalent to the whole load *w*, but merely to the friction, and the rigidity of the rope, a very great weight may be moved in this manner by a comparatively small power. If the lever have another arm to the left of G (as it appears in the figure) equal to GH, a man may then work at each end, either by pressing upon it or by pulling downwards with a cord; and thus the labourers will alternately relieve each other. Sometimes a heart-wheel has been combined with this universal lever: but it is not, we think, a combination to be recommended in practice.

If the centre of motion G were vertically above the centre of the wheel, and if another bar and hook similar and equal in length to FD hung from the point *f*, *f*G being equal to GF; these two hooks would then catch alternately into the teeth on the rising side of the wheel, and thus produce the continued rotatory motion: but this construction has a practical disadvantage; for when both bars work on the same side of the wheel, they will be in great danger of catching together and impeding each other's motions.

Universal levers have long been introduced into saw-mills, for the purpose of drawing along the logs to be sawn. See SAW-MILL, also PIPE-BORER.

LIFT TENTER. See GOVERNOR.

LINT-MILL. See FLAX-MILL.

LOADING AND UNLOADING MACHINE, an invention of

Mr. G. Davis, of Windsor, for the purpose of removing ponderous substances to or from waggons, &c. with safety and convenience. This portable machine is represented in fig. 6. pl. XV. where A is the winch turning the bar B, on which are two endless screws, or worms CC, that work in the toothed wheels DD. These wheels are fixed to the barrels EE, round which the ropes FF coil, wind up, or let out the same occasionally: the ropes pass over the pulleys GG: are brought round; and their ends, being furnished with hooks for that purpose, are hitched into staples fixed to the front of the cart, or other carriage. Within these ropes, the load H is placed on a common step-ladder I, that forms an inclined plane, up which, by turning the winch, the ropes are wound upon the barrels; and thus the load is raised into the carriage.

KK, the frame, intended to show the part of the cart, or other carriage, on which the machine is to be occasionally placed.

The whole of the barrels and cogged wheels are contained in an iron box L; the sides of which are represented in the plate, as taken off, in order that the arrangement of the different parts may be better conceived.

The pulleys on the stage (GG) may, in most cases, be affixed to the machine itself; which is adapted to every direction, and will suit carriages of every construction.

The model corresponding to the present engraving is made on the scale of about four inches to a foot; and the inventor states, that it will raise upwards of five cwt.—He is therefore confident, that his machine, when constructed of its intended size, will be capable of loading a ton weight by *one man only*; and that, even upon this enlarged plan, it does not exceed 112lb. in weight.

The Society of Arts in 1797 awarded 40 guineas to Mr. Davis, for this useful invention.

LOCK, a well-known instrument used for fastening doors, chests, &c. generally opened by a key. The lock is reckoned the masterpiece in smithery; a great deal of art and delicacy being required in contriving and varying the wards, springs, bolts, &c. and adjusting them to the places where they are to be used, and to the several occasions of using them. From the various structure of locks, accommodated to their different intentions, they acquire various names. Those placed on outer doors are called *stock-locks;* those on chamber-doors, *spring-locks;* those on trunks, *trunk-locks, padlocks,* &c.—Of these the spring-lock is the most considerable, both for its frequency and the curiosity of its structure. Its principal parts are, the main-plate, the cover-plate, and the pin-hole: to the main-plate belong

the key-hole, top-hook, cross-wards, bolt-toe or bolt-knab, draw-back-spring tumbler, pin of the tumbler, and the staples; to the cover-plate belong the pin, main-ward, cross-ward, step-ward, or dap-ward; to the pin-hole belong the hook-ward, main cross-ward, shank, the pot or bread bow-ward, and bit.

The principle on which all locks depend is the application of a lever to an interior bolt, by means of a communication from without; so that, by means of the latter, the lever acts upon the bolt, and moves it in such a manner as to secure the lid or door from being opened by any pull or push from without. The security of locks in general therefore depends on the number of impediments we can interpose betwixt the lever (the key) and the bolt which secures the door; and these impediments are well known by the name of *wards*, the number and intricacy of which alone are supposed to distinguish a good lock from a bad one. If these wards, however, do not in an effectual manner preclude the access of *all* other instruments besides the proper key, it is still possible for a mechanic of equal skill with the lock-maker to open it without the key, and thus to elude the labour of the other.

The excellence of locks consists in the security they afford; and as numberless schemes are continually brought forward by designing men, to elude every contrivance of the most ingenious mechanics, the invention of a durable lock, so constructed as to render it impossible for any person to open it without its proper key, has ever been an object of considerable importance.

In the year 1784 the *Society for the Encouragement of Arts*, &c. conferred their silver medal on Mr. Taylor, of Petworth, for his improvement on the latch or spring-bolts of common locks. This is effected by simply reversing the tumbler, so that its curved side acts against two stubs fixed on the tail of the latch, and thrusts back the latter with ease; whether the knob be turned to the right or to the left, when the lock is opened. Mr. Taylor has also behind the tail of the latch fixed a guide containing a groove, in which runs a small *friction-wheel*, that serves to keep the latch in its direct situation, and at the same time to diminish its friction: the arms of his tumbler are somewhat contracted, in order that the latch or spring-bolt may move with greater facility. By this construction, the parts of the tumbler and latch, which are in contact, move in a line, so that they pass over the greatest space under the smallest angle; and the lock itself may be constantly used for several years without requiring the application of oil.

Various patents have been obtained for the construction of locks, so as to prevent the possibility of picking them: the prin-

cipal of these is Mr. Bramah's, registered in 1784; and Mr. Spears's, in 1795: but as the account of those inventions would be unintelligible without the aid of several engravings, the curious reader will consult the 5th and 8th vols. of the *Repertory of Arts and Manufactures*, where they are minutely specified.

MANGLE, a valuable domestic machine, employed for the purpose of smoothing such linen as cannot be conveniently *ironed.*

Various patents have been granted for improvements in this machinery: but, as many of them are too complicated to be understood without very tedious details, we have annexed the figures in pl. XII. representing an improved mangle contrived by Mr. Jee, of Rotherham; to whom the Society for the Encouragement of Arts, &c. in 1798, voted their silver medal, for the ingenuity displayed on that occasion.

The following is a description of Mr. Jee's improved mangle: A (fig. 5.) points out the great wheel, which, in machines of a full size, is 15 inches in diameter. B, the arbor, on which the nut, C, is fixed. D, the handle of the winch. E, the crank, 21 inches in length. F, the rod of the crank. GG, represents the hollow studs, by which the ends of the bed are lifted up. HH, the levers. IIII, the four pulleys fixed on the moveable bed K. LL, the ends of the rollers.

Fig. 6. represents a front view of one of the hollow studs G, to show its form, when standing at the end of the bed; and into which the levers enter alternately, as often as it becomes necessary to elevate the bed, in order to put in, or take out, the rollers.

Mr. Jee's mangle is so constructed, that the handle requires to be turned one way only, in consequence of which the machine moves with greater facility, and with incomparably less injury to the linen, than by varying the turnings, and in a manner cutting the different folds. Besides, it possesses the great advantage, that a woman and one boy are sufficient to work it, and can perform as much labour in the same period of time as three or four persons with mangles of the common construction.

Mr. J. S. *Morris's* patent mangle (specification dated Feb. 1808), being compact and moderately simple, may here be described.

This mangle is constituted of four horizontal rollers, the pivots of which play on suitable supports in a stout wooden frame put together with bed-screws. To avoid circumlocution, we shall denote these four rollers by the letters A, B, C, D. The two rollers A and B, whose axles bear on brass or iron, let into

the wooden frame, are posited side by side, but not so as to touch. C is a moveable roller, about which the linen or cloth to be mangled is rolled, and it is then placed upon the rollers A and B, so as to lie in part between them. The axis of the fourth roller D works in pieces of brass or iron, which slide between two other pieces of metal, so that this roller D admits of elevation and depression, by means of a lever working upon a horizontal shaft (at the top of the frame), and chains of suspension. The pieces of metal in which the axle of the roller D runs have long vertical pieces of iron attached to them, so as to reach below all the rollers; and to hooks at the lower extremities of these irons are hung chains carrying either a rectangular platform loaded with weights, or a rectangular box containing stones or other ponderous matter.

In using this machine, the lever is pressed down and fastened by a hook; by this process the roller D, and platform below all, is elevated; then the linen to be smoothed is wrapped about the roller C, which is next laid to rest between the rollers A and B. The lever is then freed from the hook which kept it down, and the action of the ponderous matter on the platform brings the roller D into contact with the roller C: in this state a rotatory motion is applied to all the rollers by means of a winch fixed to the axle of D; and in a short time the pressure of the roller C, against A, B, and D, will give the requisite smoothness to the linen.

The patentee says, this machine will act best with a wheel on the axis of each of the cylinders A and B, and a pinion between them, with a fly-wheel on the axle of the pinion, to which motion being given, all inequalities of pressure will be conquered with great ease. This machine is not confined to mangling only, but may be used with success as a copper-plate printing press, a letter-copying machine, &c. (*Retrospect*, *No.* 15.)

The machine at MARLY, being so much celebrated, on account of its magnificence and the multiplicity of its parts, we shall here give some account of it, with a few remarks upon its construction.

This machine, which was erected by one *Rannequin*, of the country of Liege, and began to work in 1682, is situated between Marly and the village *de la Chaussée*: in that place the river is barred up, partly by the machine and partly by a dam which keeps up the water; but that the navigation may not be interrupted, two leagues above Marly a canal has been cut for the passage of boats and barges: there has also been erected (about 30 fathoms from the machine) a contrivance called an *ice-breaker*, to prevent floating pieces of ice or timber which come down the stream from damaging the machine; and the

better to secure the penstocks and the channels in which the wheels move, there is a grate of timber to stop whatever may come through the ice-breaker.

The water is raised to its destined height by means of 14 wheels, which serve to work the pumps by three different stages: first, from the river to a reservoir, at the elevation of 160 English feet above the level of the Seine: then to a second reservoir, 346 feet higher; and from the latter to the summit of a tower rather more than 533 feet above the river.

The breadth of the machine comprehends 14 jets, or water-courses, shut by sluices, or penstocks, which are raised and depressed by racks; and in each of these jets is placed a wheel: these wheels are disposed on three lines; in the first, on the side which points up the stream there are seven, six in the second, and only one in the third.

The ends of the axle of each wheel go beyond their bearing-pieces, and are bent into a crank, which makes a lever of two feet; and it is to be observed, that the crank which is towards the mountain sucks and lifts up the water of the river, to drive it into the first cistern, and the other crank gives motion to the balances.

Six of the wheels on the first line give motion by one of their cranks to an engine of eight pumps, without reckoning the feeder: these engines are compounded of a regulator, at each end of which hangs a square piece of wood, that carries and directs four pistons; the regulator is put in motion by two beams or leaders, one of which lying along answers to the crank of the wheel and a vertical regulator, and the other hanging down is united to the same regulator and to the balance.

Of the six wheels we have mentioned, there are five which by their other crank give motion to the pumps that work in the cistern of the first lift, by means of horizontal levers and chains that communicate the motion. The sixth wheel, which is the first towards the dam, moves a long chain that works the pumps of one of the wells of the upper cistern, which is called the cistern of the great *chevalets*. Each of the cranks of the seventh wheel of the first line moves a chain which goes to the first cistern.

The six wheels of the second line move, by each of their cranks, a chain that goes to the upper cistern, which (reckoning the chain that comes from the sixth wheel of the first line) makes 13 chains. These chains go over one of the cisterns of the first lift; and five of them at the same time give motion to the pistons of thirty pumps, whilst the other chains go on straight to the upper cistern.

Lastly, the wheel which is on the third line, by each of its cranks, works an engine of eight sucking and lifting pumps, and of itself supplies one conduit pipe.

The seven chains of the wheels of the first line in going along work also eight sucking pumps placed a little below the cistern of the first lift, because in that place there are the waters of a considerable spring brought thither by an aqueduct; and these same chains take up that water the second time to force it by 49 pumps into the upper reservoir, through two conduit pipes of eight inches, and three others of six inches diameter. The thirty pumps of the cistern of the first lift drive their water also through two pipes of eight inches diameter, which carry it into the upper cistern.

The water raised at the two cisterns in the way up the hill discharges itself into a great reservoir, and thence, by two conduit pipes of a foot diameter each, it runs into reservoirs of communication to be distributed into the several wells or little cisterns of the upper cistern, whence it is raised by 82 pumps, through 6 conduit pipes of 8 inches diameter, up into the tower which answers to the aqueduct.

The eight great chains that go straight to the upper cistern, without moving any engines by the way, work 16 pumps behind the upper cistern, to bring back into the reservoir of the said cistern the water which is lost out of the six pipes that go to the tower.

The eight engines which suck and lift the water from the river contain 64 pumps: the two cisterns in the way up the hill together contain 79 pumps, and the upper cisterns 82, to which adding the sucking pumps called feeders, and the 8 others which are below the midway cistern, and besides the 16 pumps which we mentioned as placed behind the upper cistern, the machine has in all 253 pumps.

The basin of the tower which receives the water raised from the river, and supplies the aqueduct, is 610 fathoms distant from the river. The water, having run along an aqueduct of 36 arches, is separated into different conduits which lead it to Marly, and formerly conveyed it also to Versailles and Trianon.

Such is the mechanism of the machine of Marly. Its mean produce is from 30,000 to 40,000 gallons of water per hour. We say *mean* produce, because, under certain favourable circumstances, it raises more than 60,000 gallons per hour. But during inundations, or when the Seine is frozen, when the water is very low, or when any repairs are making, the machine stops in great measure, if not entirely.

The annual expense of the machine, including the salaries

of those who superintend it, and the wages of the workmen employed, together with repairs, necessary articles, &c. may amount to about 3300*l.* sterling, or 9*l.* per day: which makes about 1 farthing for 90 gallons. Or, taking into the account the interest of 333,000*l.* the original expense of erection, 90 gallons will cost three halfpence, which is at the rate of a farthing for 15 gallons*.

Whoever has an opportunity of examining this machine, or peruses attentively the minute account of it given by Belidor in his second volume, will be convinced that Rannequin was an ingenious practical mechanic, but no mathematician or philosopher. In several positions the moving forces act unnecessarily obliquely, which occasions a great loss of power, and renders the machine less effectual. About $\frac{19}{20}$ of the whole moving power of some of the water-wheels are employed in giving a reciprocating motion to a set of rods and chains, which extend from the wheels to the cistern nearly three-fourths of a mile distant, where they work a set of pumps. By such injudicious construction, this engine is no less a monument of ignorance than of magnificence.

It is probable Rannequin thought his moving force would not be sufficient to raise the water to the height of 533 feet, at once; but this is not agreeable to theory: for a proper calculation would show that the force of one crank is more than sufficient to raise a cylinder of water of that altitude, and above 8 inches in diameter. To effect this with safety, however, the construction of the machine must be varied in several respects. But even according to the present construction, the water might be raised in one jet to the second reservoir. This is manifest from two experiments, one made in 1738 and the other in 1775. In the first M. Camus endeavoured to make the water rise in one jet to the tower: his attempt was not attended with success; but he made the water rise to the *foot* of the tower, which is considerably higher than the second reservoir. During this experiment the machine was prodigiously strained, and it was found necessary to secure some parts of it with chains. The object of the second trial, made in 1775, was to raise the water only to the second well. It indeed ascended thither at different times, and in abundance: but the pipes were exceedingly strained at the bottom, so that several of them burst; and it was necessary to suspend and recommence the experiment

* This is very far from the price which the king of Denmark thought he might set on this water; for that prince, when he visited Marly in 1769, being astonished at the immense magnitude of the machine, the multiplicity of its movements, and the number of workmen it employed, conjectured that the water probably cost as much as wine.

several times. This however arose from the age of the tubes and their want of strength, a fault which might easily have been remedied. Hence, it results from this trial, that the chains which proceed from the river to the first well might be suppressed, together with the first well itself: and this perhaps is all that is to be expected without a complete change in the machinery *.

MILL, properly denotes a machine for *grinding* or pulverizing substances, as corn, &c.; but, in a more general signification is now applied to many machines whose action arises in a great measure from a circular motion. Of these there are various kinds described in different parts of this volume, as *Bark-mill, Barker's-mill, Flax-mill, Flour-mill, Foot-mill, Hand-mill, Kneading-mill, Oil-mill, Paper-mill, Saw-mill, Tide-mill, Water-mill, &c.*

As a well-constructed, yet cheap, family-mill cannot but be highly useful in many parts of the country, we shall here present a description of the *Family-mill and Bolter* of Mr. T. Rustall, of Purbrook-heath, near Portsmouth, who received a premium of 40 guineas from the Society of Arts for his invention †.

In pl. XX. fig. 4. A, is the handle of the mill; B, one of the mill-stones, which is about 30 inches in diameter, and 5 inches in thickness, moving with its axis C: D, is the other mill-stone, which, when in use, is stationary; but which may be placed near to, or at a distance from, the moveable stone B, by means of three screws passing through the wooden block E, that supports one end of the axis C; after it has been put through a hole or perforation in the bed stone. The grain likwise passes through this perforation from the hopper F, into the mill. F, represents the hopper, which is agitated by two iron pins on the axis C, that alternately raise the vessel containing the grain, which again sinks by its own weight. In consequence of this motion the corn is conveyed through a spout that passes from such hopper into the centre of the mill behind, and through the bed stone D. G, a paddle, regulating the quantity of corn to be delivered to the mill; and, by raising or lowering which, a larger or smaller proportion of grain may be furnished: H, the receptacle for the flour, into which it falls from the mill-stones, when ground: I, represents one of the two wooden supporters on which the bedstone, D, rests. These are screwed to the

* M. Hachette informs us, *Traité Elémentaire des Machines*, p. 105, that this machine, after having stood 128 years, is now in an irreparable state of ruin.

† Mr. Rustall engages to furnish the whole apparatus, and deliver it free of carriage, in London, for the moderate price of *twenty guineas*.

block E, and likewise mortised into the lower frame-work of the mill at K, which is connected by means of the pins or wedges L, L, L, that admit the whole mill to be easily taken to pieces: M, a fly-wheel, placed at the furthest extremity of the axis C, and on which another handle may be occasionally fixed; N, a small rail, serving to keep the hopper in its place; the furthest part of such hopper resting on a small pin, which admits of sufficient motion for that vessel to shake forward the corn: O, a spur-rail, for strengthening the frame-work of the mill; P, the front upright, that is mortised into the frame-work, and serves as a rest for the end of the iron axis C, which is next to the handle. On each extremity of such axis there is a shoulder, which keeps it steady in its place. Lastly, there is a cloth-hood fixed to a broad wooden hoop, which is placed over the stones while working, to prevent the finer particles of flour from escaping.

Fig. 5. represents the bolter, with its front removed, in order to display its interior structure; the machine being 3 feet 10 inches in length, $19\frac{1}{2}$ inches in breadth, and 18 inches in depth. A, is a moveable partition, sliding about four feet backwards or forwards, from the centre of the box, upon two wooden ribs, which are fixed to the back and front of the box, and one of which is delineated at the letter B; C, the lid of the bolter, represented open; D, a slider, which is moveable in a groove made in the lid, by means of two handles on the back of such lid; E, a forked iron, fixed in the slider D, and which, when the lid is shut, takes hold of the edge of the sieve F, and moves it backwards and forwards on the wooden ribs B, according to the agitation of the slider; G, represents a fixed partition in the lower centre of the box, which it divides into two parts, in order to separate the fine from the coarse flour; from this partition the slider A moves each way about four inches, and thus affords room for working the sieve: H, a board that is parallel to the bottom of the bolter, and forms part of the slider A; this board serves to prevent any of the sifted matter from falling into the other partition: I, represents two of the back feet, which support the bolter.

Fig. 6. of the plate above mentioned is a view of the top, or upper part, of the lid of the bolter; K, the slider that moves the lengthwise of the bolter; L, L, the handles, by which the slider is worked; M, a screw, serving to hold the fork, which imparts motion to the sieve.

Fig. 7. represents the forked iron, E, separately from the lid.

Both the mill and bolter may be constructed at a moderate expense, and they occupy only a small space of ground. The former may even be worked in a public kitchen, or within a

room in a farm-house, without occasioning any great incumbrance.

The particular excellence of the mill consists in this circumstance, that, from the vertical position of its stones, it may be put in action without the intervention of cogs or wheels. It may be employed in the grinding of malt, the bruising of oats for horses, and for making flour, or for all these purposes: it may likewise be easily altered, so as to grind either of those articles to a greater or less degree of fineness.

Another advantage peculiar to Mr. Rustall's contrivance is, that one man is sufficient to work it; though, if two persons, namely, a man and a boy, be employed, they will be able to produce, in the course of two hours, a quantity of flour sufficient to serve a family, consisting of six or eight persons, for a whole week:—repeated satisfactory trials have proved that this mill grinds the corn completely, and at the rate of one bushel of wheat within the hour. Besides, the industrious farmer will thus be enabled to make comparative experiments on the quality of his grain, and may furnish himself, at a trifling expense, with flour from his own wheat, without apprehending any adulteration; or without being exposed to the impositions or caprice of fraudulent and avaricious millers.

Lastly, though Mr. R.'s bolter be more particularly calculated for sifting flour, it may also be applied to various other useful purposes, and especially with a view to obviate the inconveniences necessarily attendant on the levigation of noxious substances, and to prevent the waste of their finer particles.

The subject of mill-work has engaged the attention of many authors in different countries: the following is a catalogue of the chief writings, both theoretical and descriptive.

Künstliche abriss, allerhand wasser- wind- ross- und handmuhlen, &c. von *Jacob. de Strada à Rosberg.* 1617.

Georg Christoph Luerner Machina toreutica nova; oder, beschreibung der neu erfundenen Drehmühlen. 1661.

Theatrum machinarum novum; das ist, neu vermehrter Schauplatz der mechanischen Künste, handelt von allerhand wasser- wind-ross- gewicht-und hand-muhlen. Von *Geo. And. Bocklern.* 1661.

Contenta discursus mechanici, concernentis descriptionem optimæ formæ velorum horizontalium pro usu molarum, nec non fundamentum inclinatorum velorum in navibus, habita coram Societate Regia, a R. H. translata ex collectionibus philosophicis M. Dec. num. 3. pa. 61. 1681.

Dissertatio historica de molis, quam præside *Joh. Phil. Treuer* defend. *Jo. Tob. Mühlberger* Ratisbonens. Jenae. 1695.

Martin Marien's Wiskundige beschouwinge der wind—of

wadermoolens, vergeleken met die van den heer *Johann Lulofs*. Amsterdam. 1700.

Vollständige mühlen-baukunst, von *Leonhard Christoph. Sturm*. 1718.

Jacob Leupold's Theatrum machinarum. 1724, 1725.

Remarques sur les aubes ou pallettes des moulins, et autres machines mues par le courant des rivières. Par *M. Pitot*, mem. Acad. Roy. Paris. 1729.

Joh. van Zyl theatrum machinarum universale, of groot algemeen moolen-bock, &c. Amsterdam. 1734.

Jo. Caral. Totens Disser. de machinis molaribus optime constreündis. Lugd. Batav. 1734.

Kurze, aber deutliche anweisung zur construction der wind- und wasser-muhlen, von *Gottfr. Kinderling*. 1735.

Desaguliers's Experimental philosophy. 1735, 1744.

Architecture hydraulique, par *M. Belidor*. 1737, 1753.

Part of a letter from Mr. W. Anderson, F. R. S. to Mr. Baker, F. R. S. containing a description of a water-wheel for mills invented by Mr. *Philip Williams*. Phil. Trans. vol. 44. 1746.

Leonh. Euleri, De constructione aptissima molarum alatarum disp. Nov. Com. Acad. Petrop. tom. 4. 1752.

Mémoire dans lequel on démontre que l'eau d'une chûte destinée à faire mouvoir quelque machine, moulin ou autre, peut toujours produire beaucoup plus d'effet en agissant par son poids qu'en agissant par son choc, et que les roues à pots qui tournent lentement produisent plus d'effet que celles qui tournent vîte, relativement aux chûtes et aux dépenses. Par *M. de Parcieux*, Acad. Roy. Paris, 1756.

Jo. Alberti Euleri Enodatio questionis: quo modo vis aquæ aliusve fluidi cum maximo lucro ad molas circumagendas, aliave opera perficienda impendi possit, præmio à societate Regia. Sci. Gotting. 1754.

Recherches plus exactes sur l'effet des moulins à vent, par *M. Euler*. Hist. Acad. Roy. Berlin. 1756.

An experimental inquiry concerning the natural powers of wind and water to turn mills and other machines depending on a circular motion. By Mr. *J. Smeaton*, F. R. S. Phil. Trans. 1759.

[Abstracts of this and Mr. Smeaton's other papers on water and wind-mills have been given in book iv. of our first volume, and the Introduction to this. They were collected and published by Taylor, Holborn, in 1794.]

Mémoire dans lequel on prouve que les aubes roues mûes par les courans des grandes rivières feroient beaucoup plus d'effet si elles étoient inclinées aux rayons, qu'elles ne font étant

appliquées contre les rayons mêmes, comme elles le sont aux moulins pendans et aux moulins sur bateaux qui sont sur les rivières de Seine, de Marne, de Loire, &c. Par *M. de Parcieux*, mem. Acad. Roy. Paris. 1759.

Joh. Albert Euler's Abhandlung von der bewegung ebener flächen, wenn sie vom winde getrieben werden. 1765.

Schauplatz des mechanischen mühlenbaues, darinnen von verschiedenen hand- trett- ross- gewicht- wasser- und wind-mühlen gehandelt wird, durch *Johann George Scopp* I. C. iter Theil. 1766.

Theatrum machinarum molarium, oder schauplatz der mühlenbaukunst. als der neunte theil von des sel hern *Jac. Leupolds* theatro machinarum, von *Joh. Mathias Beyern.* 1767, 1788, 1802.

A memoir concerning the most advantageous construction of water-wheels, &c. by Mr. *Mallet*, of Geneva. Phil. Trans. 1767.

Mémoire sur les roues hydrauliques, par M. le Chevalier *de Borda*, mem. Acad. Roy. Paris. 1767.

Kurzer unterricht, allerley arten von wind-und wasser-mühlen auf die vortheilhafteste weise zu erbauen, nebst einigen gedanken über die verbesserung des räderwerks an den mühlen, von *Joh. König*. 1767.

G. G. Bischoff's Beyträge zur mathesis dur muhlen. 1767.

Sur la position des ailes des moulins à vent. *D'Alembert.* Opusc. mathema. tom. 5. 1768.

Determination générale de l'effet des roues mûes par le choc de l'eau, par M. l'abbé *Bossut*, mem. Acad. Roy. Paris. 1769.

Andreas Kaovenhöfer, Deutliche abhandlung von den rädern der wassermühlen, und von dem einrandigen werke der schneidemühlen. 1770.

Manuel du meûnier et du charpentier des moulins, redige par *Edm. Bequillet.* 1775.

Rémarques sur les moulins à vent, par *M. Lambert.*

Rémarques sur les moulins et autres machines, où l'eau tombe en dessus de la roue, par *M. Lambert.*

Experience et rémarques sur les moulins que l'eau meut par en bas dans une direction horizontale, par *M. Lambert.*

Rémarques sur les moulins et autres machines dont les roues prennant l'eau à une certaine hauteur, par *M. Lambert.*

[The last four articles are inserted in Mem. Acad. Roy. Berlin. 1775.]

Of the degrees and quantities of winds requisite to move the heavier kinds of wind-machines, by *John Stedmann*, M.D. Phil. Trans. 1777.

Ausführliche erklärung der vorschläge für die längere dauer der muhlenwerke, nebst ähnlichen gegenstanden, in ein gespräch verfasset, von *Johann Christian Füllmann*, Muhlenmeister. 1780.

Observations théoriques et experimentales sur l'effet des moulins à vent, et sur la figure de leurs ailes, par *M. Coulumb*, mem. Acad. Roy. Paris. 1781.

Tratado de los granos y modo de molerlos con economia, de la conservacion de astos y de las hairnas ; escr. en. Fr. par M. *Beguillet*, y extract. y trad. al Cast. con algun notas y un supplem. por *Ph. Marescaulchi*. 1786.

Suite de l'architecture hydraulique, par *M. Fabre*. 1786.

Mémoires sur les moyens de perfectionner les moulins, et la mouture économique, par *C. Bucquet*. 1786.

Manuel ou vocabulaire des moulins à pot. A Amst. 1786.

Die nothigsten kenntnisse zur anlegung, beurtheilung und berechnung der wassermühlen, und zwar der mahl- oehl- und säge-mühlen, sür anfänger und liebhaber der mühlenbaukunst, von *Joh. Christ. Huth*. 1787.

An essay proving iron far superior to stone of any kind for breaking and grinding of corn, &c. by *W. Walton*. 1788.

Mühlenpraktik, oder unterricht in dem mahlen der brodfrüchte, für polizeybeamte, gaverksleute und hauswirthe, von *L. Ph. Hahn*. 1790.

The young mill-wright and miller's guide, by *Oliver Evans*. Philadelphia. 1790.

Manuel du müenier et du constructeur des moulins à eau et à grains, par *C. Bucquet*. 1791.

Praktische anweisung zum mühlenbau, von *Lr. Clausen*. 1792.

Beschreibung zweir maschinen zur reinigung des korns, von *Lr. Clausen*. 1792.

Instructions sur l'usage des moulins à bras, inventés et perfectionnés par les Citoyens *Durand* père et fils, mécaniciens. 1792.

Theoretisch-praktische abhandlung über die besserung der muhlräder von dem verfasser de zweekmässigen luftreiniger, &c. 1795.

A treatise on mills, in four parts, by *John Banks*. 1795.

Handbuch der maschinenlehre, sur praktiker und akademische lehrer, von *Karl Christian Langsdorf*. 1797, 1799.

On the power of machines: including Barker's-mill, Westgarth's engine, Cooper's-mill, horizontal water-wheel, &c. by *John Banks*. 1803.

The experienced millwright, by *Andrew Gray*, millwright. 1804.

Practical Essays on Mill Work, and other Machinery, and on the Shafts of Mills, by *Robertson Buchanan*, Civil Engineer, 1814. A new edition of this useful work has been recently published, with great improvements, by Mr. Tredgold.

The Transactions of the Society of Arts and Manufactures; several of the volumes of which contain improvements in mill-work. See also the Repertory of Arts, in various places.

MULLERS for grinding colours, according to the common construction, are too well known and too simple to need a particular description here. But Mr. James Rawlinson, of Derby, has invented a *concave* muller, for which the Society of Arts presented him a silver medal and ten guineas, on account of its ingenuity. He has used his machine for several years, and has found it much more effectual and expeditious in reducing the colour to extreme fineness than the usual method, and much less injurious to the health of the workman, who frequently has done as much with it in three hours as he could in twelve with the muller and slab.

The machine consists of a flat cylinder of black marble, sixteen inches and a half diameter, and four and a half thickness, with an axle traversing its centre (thus somewhat resembling a common cutler's grindstone). It is suspended on a similar frame, in a vertical position, and turned round in the same manner by a winch: a concave piece of marble is provided, of the same breadth as the circular stone, forming a segment of the same circle one third of the circumference in extent: this, which may be considered as the muller, is fitted into a piece of solid wood of similar shape, one end of which is secured loosely by a hinge or otherwise to the frame; the other end, rising over the circular stone and supported by it, is further pressed down on it by a long spring bent over from the opposite extremity of the stand, and regulated as to its pressure by a screw, whose end turns against the concave muller: a slight frame of iron in front, moveable on a hinge, by which it is secured to the frame, supports a scraper, for taking off the colour, formed of a piece of watch-spring, which is turned back out of the way when not in use. Mr. R. thinks the circular grindstones might be made much larger than he used, to advantage, and that one of two feet diameter would not occasion too much labour to one man to turn it: he computes that in his machine there are seventy square inches of surface of the concave muller in constant work on the paint, while in the common muller not more than sixteen square inches are usually in contact with the slab. The machine will be found equally serviceable for the colours ground in water as for those prepared with oil, according to Mr. R., who highly recommends its use to all colourmen.

Mr. R. advises, in making up the colours in bladders, to insert a bit of quill or reed in the neck of the bladder, which will thus bind better in tying; and, admitting of a secure stopper, will be more cleanly and less wasteful than the usual method of stopping with a nail, and keep the colour more safe from the air. (Retrospect, &c. No. I.)

NORIA. See HYDRAULIC-*machines*, No. 3.

ODOMETER, a mechanical contrivance for measuring the way passed over by a carriage. An apparatus of this kind, by Mr. R. L. Edgworth, may be easily attached to the axle-tree bed of a post-chaise, gig, or any other carriage. One turn and a half of a screw is formed round the nave of one of the hinder wheels by a slip of iron, which is wound round the nave, and fastened to it by screws passing through five or six cocks, that are turned up at right angles on the slip of iron. The helix so formed on the nave of the carriage-wheel acts as a worm or screw upon the teeth of a wheel called A, which should have 20 teeth, if the carriage-wheel be 5 feet 3 inches in circumference. On the arbor of the wheel A there is a brass endless screw called B, which acts upon a brass wheel c of 80 teeth; this latter wheel serving as a dial plate, and is divided into miles, halves, quarters, and furlongs. The figures indicating the miles are nearly $\frac{3}{4}$ of an inch long, so as to be quite distinct; they are pointed to an index which projects from a fixed point a little way over the plate, in such a manner as to be easily seen from the carriage, as well as the figures passing successively beneath it. The two brass wheels A and C are mounted by irons with pivots upon a rectangular block of wood, which is to be screwed upon the axletree bed, and, if the carriage permits, in such a manner that the dial-plate may front the eye of the person who looks from the carriage.

There is a ratchet-wheel attached to the arbor of the wheel A, which by means of a click allows the wheel to be set with a key or handle fitted to the square end of the arbor. There are two springs, one adapted to the wheel A, and the other to the dial-plate wheel c, to prevent them from shaking by the motion of the carriage.

Such an apparatus will estimate distances for 5 miles, and an additional wheel of 81 teeth would render it fit to count 400 miles. If the carriage-wheel be either larger or smaller than 5 feet 3 inches in perimeter, it will still be easy to adapt an odometer to it.

OIL-MILL, a mill for expressing the oils from fruits, or grains, &c. As these kingdoms do not produce the olive, it would be needless to describe the mills which are employed in the southern parts of Europe. We shall content ourselves,

therefore, with a description of a Dutch oil-mill, employed for grinding and pressing lint-seed, rape-seed, and other oleaginous grains. Further, to accommodate our description still more to our local circumstances, we shall employ water as the first mover; thus avoiding the enormous expense and complication of a windmill.

In plate XXI. fig. A.

1. Is the elevation of a wheel, over or under-shot, as the situation may require.

2. The bell-metal socket, supported by masonry, for receiving the outer gudgeon of the water-wheel.

3. The water-course.

Fig. B.

1. A spur-wheel upon the same axis, having 52 teeth.

2. The trundle that is driven by No. 1. and has 78 staves.

3. The wallower, or axis for raising the pestles. It is furnished round its circumference with wipers for lifting the pestles, so that each may fall twice during one turn of the water-wheel, that is, three wipers for each pestle.

4. A frame of timber, carrying a concave half-cylinder of bell-metal, in which the wallower (cased in that part with iron plates) rests and turns round.

5. Masonry supporting the inner gudgeon of the water-wheel and the above mentioned frame.

6. Gudgeon of the wallower, which bears against a bell-metal step fixed in the wall. This double support of the wallower is found to be necessary in all mills which drive a number of heavy stampers.

Fig. C, is the elevation of the pestle and press-frame, their furniture, the mortars, and the press-pestles.

1. The six pestles.

2. Cross pieces between the two rails of the frame, forming, with these rails, guides for the perpendicular motion of the pestles.

3. The two rails. The back one is not seen. They are checked and bolted into the standards No. 12.

4. The tails of the lifts, corresponding to the wipers upon the wallower. See the article Wiper.

5. Another rail in front, for carrying the detents which hold up the pestles when not acting. It is marked 14 in fig. M.

6. A beam a little way behind the pestles. To this are fixed the pulleys for the ropes which lift and stop the pestles. It is represented by 16 in fig. M.

7. The said pulleys with their ropes.

8. The driver, which strikes the wedge that presses the oil.

9. The discharger, a stamper which strikes upon the inverted wedge, and loosens the press.

10. The lower rail with its cross pieces, forming the lower guides of the pestles.

11. A small cog-wheel upon the wallower, for turning the spatula, which stirs about the oil-seed in the chauffer-pan. It has 28 teeth, and is marked No. 6. in fig. M.

12. The four standards, mortised below into the block, and above into the joists and beams of the building.

13. The six mortars hollowed out of the block itself, and in shape pretty much like a kitchen pot.

14. The feet of the pestles, rounded into cylinders, and shod with a great lump of iron.

15. A board behind the pestles, standing on its edge, but inclining a little backwards. There is such another in front, but not represented here. These form a sort of trough, which prevents the seed from being scattered about by the fall of the pestles, and lost.

16. The first press-box (also hollowed out of the block, in which the grain is squeezed, after it has come for the first time from below the mill-stones.

17. The second press-box, at the other end of the block, for squeezing the grain after it has passed a second time under the pestles.

18. Frame of timber for supporting the other end of the wallower, in the same manner as at No. 4. fig. B.

19. Small cog-wheel on the end of the wallower, for giving motion to the mill-stones. It has 28 teeth.

20. Gudgeon of the wallower, bearing on a bell-metal socket fixed in the wall.

21. Vessels for receiving the oil from the press-boxes.

Fig. D. Elevation and mechanism of the mill-stones.

1. Upright shaft, carrying the great cog-wheel above, and the runner mill-stones below in their frame.

2. Cog-wheel of 76 cogs, driven by No. 19. of fig. C.

3. The frame of the runners.

4. The innermost runner, or the one nearest the shaft.

5. Outermost ditto, being further from the shaft.

6. The inner rake, which collects the grain under the outer runner.

7. The outer-rake, which collects the grain under the inner runner. In this manner the grain is always turned over and over, and crushed in every direction. The inner rake lays the grain in a slope, of which fig. O is a section; the runner flattens it, and the second rake lifts it again, as is marked in fig. P; so that every side of a grain is presented to the mill-stone, and the rest of the legger or nether mill-stone is so swept by them, that

not a single grain is left on any part of it. The outer-rake is also furnished with a rag of cloth, which rubs against the border or hoop that surrounds the nether mill-stone, so as to drag out the few grains which might otherwise remain in the corner.

8. The ends of the iron axle which passes through the upright shaft, and through the two runners. Thus they have two motions: 1mo, A rotation round their own axis; 2do, That by which they are carried round upon the nether mill-stone on which they roll. The holes in these mill-stones are made a little wide; and the holes in the ears of the frame, which carry the ends of the iron axis, are made oval up and down. This great freedom of motion is necessary for the runner mill-stones, because frequently more or less of the grain is below them at a time, and they must therefore be at liberty to get over it without straining, and perhaps breaking, the shaft.

9. The ears of the frame which lead the two extremities of the iron axis. They are mortised into the under side of the bars of the square frame, that is carried round with the shaft.

10. The border or hoop which surrounds the nether millstone.

11. and 12. The nether millstone, and masonry which supports it.

Fig. K. Plan of the runner mill-stones, and the frame which carries them round.

1, 1. Are the two mill-stones.

3, 3, 3, 3. The outside pieces of the frame.

4, 4, 4, 4. The cross-bars of the frame which embrace the upright shaft 5, and give motion to the whole.

6, 6. The iron axis upon which the runners turn.

7. The outer-rake.

8. The inner ditto.

Fig. L. Represents the nether mill-stone seen from above.

1. The wooden gutter, which surrounds the nether millstone.

2. The border or hoop, about six inches high, all round, to prevent any seed from being scattered.

3. An opening or trap-door in the gutter, which can be opened or shut at pleasure. When open, it allows the bruised grain collected in and shoved along the gutter by the rakes to pass through into troughs placed below to receive it.

4. Portion of the circle described by the outer runner.

5. Portion of the circle described by the inner one. By these we see that the two stones have different routes round the axis, and bruise more seed.

6. The outer rake.

7. The inner ditto.

8. The sweep, making part of the inner rake, occasionally let down for sweeping off all the seed when it has been sufficiently bruised. The pressure and action of these rakes is adjusted by means of wooden springs, which cannot be easily and distinctly represented by any figure. The oblique position of the rakes (the outer point going foremost) causes them to shove the grain inwards or toward the centre, and at the same time to turn it over, somewhat in the same manner as the mould-board of a plough shoves the earth to the right hand, and partly turns it over. Some mills have but one sweeper; and, indeed, there is great variety in the form and construction of this part of the machinery.

Fig. M. Profile of the pestle frame.

1. Section of the horizontal shaft.
2. Three wipers for lifting the pestles. See WIPER.
3. Little wheel of 28 teeth, for giving motion to the spatula.
4. Another wheel, which is driven by it, having 20 teeth.
5. Horizontal axle of ditto.
6. Another wheel on the same axle, having 13 teeth.
7. A wheel upon the upper end of the spindle, having 12 teeth.
8. Two guides, in which the spindle turns freely, and so that it can be shifted higher and lower.
9. A lever, moveable round the piece No. 14. and having a hole in it at 9, through which the spindle passes, turning freely. The spindle has in this place a shoulder, which rests on the border of the hole 9; so that by the motion of this lever the spindle may be disengaged from the wheel-work at pleasure. This motion is given to it by means of the lever 10, 10, moveable round its middle. The workman employed at the chauffer pulls at the rope 10, 11, and thus disengages the spindle and spatula.
11. A pestle seen sidewise.
12. The lift of ditto.
13. The upper rails, marked No. 3. in fig. c.
14. The rail, marked No. 5. in fig. c. To this are fixed the detents, which serve to stop and hold up the pestles.
15. A detent, which is moved by the rope at its outer end.
16. A bracket behind the pestles, having a pulley, through which passes the rope going to the detent 15.
17. The said pulley.
18. The rope at the workman's hand, passing through the pulley 17, and fixed to the end of the detent 15.

This detent naturally hangs perpendicular by its own weight. When the workman wants to stop a pestle, he pulls at the rope 18, during the rise of the pestle. When this is at its greatest

height, the detent is horizontal, and prevents the pestle from falling by means of a pin projecting from the side of the pestle, which rests upon the detent, the detent itself being held in that position by hitching the loop of the rope upon a pin at the workman's hand.

19. The two lower rails, marked No. 10. fig. c.

20. Great wooden, and sometimes stone, block, in which the mortars are formed, marked No. 21. in fig. c.

21. Vessel placed below the press-boxes for receiving the oil.

22. Chauffer, or little furnace, for warming the bruised grain.

23. Backet in the front of the chauffer, tapering downwards, and opening below in a narrow slit. The hair bags, in which the grain is to be pressed after it has been warmed in the chauffer, are filled by placing them in this backet. The grain is lifted out of the chauffer with a ladle, and put into these bags; and a good quantity of oil runs from it through the slit at the bottom into a vessel set to receive it.

24. The spatula attached to the lower end of the spindle, and turning round among the grain in the chauffer-pan; thus preventing it from sticking to the bottom or sides, and getting too much heat.

The first part of the process at an oil-mill is bruising the seed under the runner stones*. That this may be more expeditiously done, one of the runners is set about $\frac{2}{3}$ds of its own thickness nearer the shaft than the other. Thus they have different treads; and the grain, which is a little heaped towards the centre, is thus bruised by both. The inner rake gathers it up under the outer stone into a ridge, of which the section is represented in plate XXI. fig. o. The stone passes over it, and flattens it. It is gathered up again into a ridge, of the form of fig. P, under the inner stone, by the outer rake, which consists of two parts. The outer part presses close on the wooden border which surrounds the nether stone, and shoves the seed obliquely inwards, while the inner part of this rake gathers up what had spread toward the centre. The other rake has a joint near the middle of its length, by which the outer half of it can be raised from the nether stone, while the inner half continues pressing on it, and thus scrapes off the moist paste. When the seed is sufficiently bruised, the miller lets down the outer end of the rake. This immediately gathers the whole paste, and shoves it obliquely outwards to the wooden rim, where it is at last brought

* We are told, that in a mill at Reichenhoffen, in Alsace, a considerable improvement has been made by passing the seed between two small iron rollers, before it is put under the mill-stones. A great deal of work is said to be saved by this preliminary operation, and finer oil produced: which we think very probable. The stamping and pressing go on as in other mills.

to a part that is left unboarded, and it falls through into troughs placed to receive it. The troughs have holes in the bottom, through which the oil drips all the time of the operation. This part of the oil is directed into a particular cistern, being considered as the purest of the whole; having been obtained, without pressure, by the mere breaking of the hull of the seed.

In some mills this operation is expedited, and a much greater quantity of this best oil is obtained, by having the bed of masonry which supports the legger formed into a little furnace, and gently heated. But the utmost care is necessary to prevent the heat from becoming considerable. This, enabling the oil to dissolve more of the fermentable substance of the seed, exposes the oil to the risk of growing soon very rancid; and, in general, it is thought a hazardous practice, and the oil does not bring so high a price.

When the paste comes from under the stones it is put into the hair bags, and subjected to the first pressing. The oil thus obtained is also esteemed as of the first quality, scarcely inferior to the former, and is kept apart: (the great oil cistern being divided into several portions by partitions).

The oil cakes of this pressing are taken out of the bags, broken to pieces, and put into the mortars for the first stamping. Here the paste is again broken down, and the parenchyma of the seed reduced to a fine meal. Thus free egress is allowed to the oil from every vesicle in which it is contained. But it is now rendered much more clammy, by the forcible mixture of the mucilage, and even of the finer parts of the meal. When sufficiently pounded, the workman stops the pestle of a mortar, when at the top of its lift, and carries the contents of the mortar to the first chauffer pan, where it is heated to about the temperature of melting bees-wax (this, we are told, is the test), and all the while stirred about by the spatula. From thence it is again put into hair bags, in the manner already described; and the oil which drips from it during this operation is considered as the best of the second quality, and in some mills is kept apart. The paste is now subjected to the second pressing, and the oil is that of the second quality.

All this operation of pounding and heating is performed by one workman, who has constant employment by taking the four mortars in succession. The putting into the bags and conducting of the pressing gives equal employment to another workman.

In the mills of Picardy, Alsace, and most of Flanders, the operation ends here; and the produce from the chauffer is increased, by putting a spoonful or two of water into the pan among the paste.

But the Dutch take more pains. They add no water to the paste of this their first stamping. They say that this greatly lowers the quality of the oil. The cakes which result from this pressing, and are there sold as food for cattle, are still fat and softish. The Dutch break them down, and subject them to the pestles for the second stamping. These reduce them to an impalpable paste, stiff like clay. It is lifted out, and put into the second chauffer pan; a few spoonfuls of water are added, and the whole kept for some time as hot as boiling water, and carefully stirred all the while. From thence it is lifted into the hair bags of the last press, subjected to the press; and a quantity of oil of the lowest quality is obtained, sufficient for giving a satisfactory profit to the miller. The cake is now perfectly dry, and hard, like a piece of board, and is sold to the farmers. Nay, there are small mills in Holland which have no other employment than extracting oil from the cakes which they purchase from the French and Brabanters; a clear indication of the superiority of the Dutch practice.

The nicety with which that industrious people conduct all their business is remarkable in this manufacture.

In their oil cistern, the parenchymous part, which unavoidably gets through, in some degree, in every operation, gradually subsides; and the liquor, in any division of the cistern, comes to consist of strata of different degrees of purity. The pumps which lift it out of each division are in pairs; one takes it up from the very bottom, and the other only from half the depth. The last only is barrelled up for the market, and the other goes into a deep and narrow cistern, where the dreg again subsides, and more pure oil of that quality is obtained. By such careful and judicious practices, the Dutch not only supply themselves with this important article, but annually send considerable quantities even into those provinces of France and Flanders where they bought the seed from which it was extracted. When we reflect on the high price of labour in Holland, on the want of timber for machinery, on the expense of building in that country, and on the enormous expense of wind-mill machinery, both in the first erection and the subsequent wear and tear, it must be evident, that oil-mills erected in England on water falls, and after the Dutch manner, cannot fail of being a great national advantage. The chatellanie or seigneurie of Lille alone makes annually between 30,000 and 40,000 barrels, each containing about 26 gallons.

What is here delivered is only a sketch. Every person acquainted with machinery will understand the general movements and operations. But the intelligent mechanic well knows, that operations of this kind have many minute circumstances

which cannot be described, and which, nevertheless, may have a great influence on the whole. The rakes in the bruising-mill have an office to perform which resembles that of the hand, directed by a careful eye and unceasing attention. Words cannot communicate a clear notion of this; and a mill, constructed from the best drawings, by the most skilful workman, may gather the seed so ill, that the half of it shall not be bruised after many rounds of the machinery. This produces a scanty return of the finest oil; and the mill gets a bad character. The proprietor loses his money, is discouraged, and gives up the work. —There is no security but by procuring a Dutch mill-wright, and paying him with the liberality of Britons. Such unhoped-for tasks have been performed of late years by machinery; and mechanical knowledge and *invention* are now so generally diffused, that it is highly probable that we should soon excel our teachers in this branch. But this very diffusion of knowledge, by encouraging speculation among the artists, makes it a still greater risk to erect a Dutch oil-mill without having a Dutchman, acquainted with its most improved present form, to conduct the work. *(Supp. Encyclo. Britan.)* Another description of an oil-mill may be seen in the PANTOLOGIA, vol. viii.

Boring of ORDNANCE. Till within a few years, iron ordnance were cast with a cylindrical cavity, nearly of the dimensions of the caliber of the piece, which was afterwards enlarged to the proper caliber by means of steel-cutters fixed into the dog-head of a boring bar-iron. Three equidistant side-cutters were requisite to preserve the caliber straight and cylindrical; and a single cutter was used at the end of the bar to smooth the breach of the piece. In boring ordnance cast hollow, the piece was fixed upon a carriage that could be moved backwards and forwards in a direct line with the centre of a water-wheel; in this centre was fixed the boring-bar, of a sufficient length to reach up to the breech of the piece, or more properly to the further end of the caliber. The carriage with the piece being drawn backwards from the centre of the water-wheel to introduce the boring and finishing bars and cutters, it is then pressed forwards upon this bar by means of levers, weights, &c. and the water-wheel being set going, the bar and fullers are turned round, and clean out and smooth the caliber to its proper dimensions.

Experience at last pointed out many inconveniences arising from the method of casting guns *hollow*, and widening the calibers by these boring bars. For the body of iron of the hollow gun, being, at casting, in contact with the core that made the caliber within-side, and with the mould without-side, began to

consolidate towards these sides in the first place sooner than in the intermediate space, where of course the contraction of the iron takes place; by which means, all guns cast hollow became more or less spongy where they ought to have been most compact; and numberless cavities also were created round the cores, from stagnated air generated in them, which were too deep to be cut out by the boring.

To remedy these defects, iron ordnance as well as brass is now universally cast solid, by which means the column of metal is greatly enlarged, and the grain more compressed; and the contraction becomes in the heart of the column, and consequently is cut out by the perforation for the caliber.

Guns are bored out of the solid reversely from the hollow method. The piece A (pl. XXI.) is placed upon two standards BB, by means of two journeys, turned round by a water-wheel; the breech D being introduced into the central line of the wheel, with the muzzle towards the sliding carriage E, which is pressed forwards by a ratch F, and weights in the same way as the gun-carriage was in hollow-boring. Upon this sliding carriage is fixed, truly horizontal and central to the gun, the drill-bar G, to the end of which is fixed a carp's tongue drill or cutter H; which, being pressed forward upon the piece whilst it is turning round, perforates the bore, which is afterwards finished with bars and cutters as the hollow guns were.

The machinery for boring of ordnance is sometimes put in motion by a steam-engine: and in this way, from 18 to 24 great guns have been boring at the same time; the borer in each piece being brought up to its proper place in the gun, by a lever and weights. In this method of bringing up the borer the pressure may always be made equable, and the motion of the borer regular; but the disadvantage is, that without due attention the borer may work up too far towards the breech, and the piece be spoiled. In the Royal Arsenal at Woolwich, only one piece is bored at a time in the same mill: the gun to be bored lies with its axis parallel to the horizon, and in that position is turned round its axis by means of wheel-work, moved by one or more horses. The borer is laid as above described, in the direction of the axis of the gun, and is incapable of motion in any direction except that of its length; and in this direction it is constantly moved by means of a small rack-wheel, kept in proper motion by two men, who thus make the point of the borer so to bear against the part of the gun that is boring, as to pierce and cut it. The outside of the gun is smoothed at the same time by men with instruments fit for the purpose, whilst it turns round, so that the bore may be exactly in the centre of the metal.

In this way the boring is performed with great nicety, the guns scarcely ever failing in the examination. But in these mills the horses work to great disadvantage, the diameters of the walks in which they move being far too small. See the introductory part of this volume, art. 76.

PARALLEL MOTION, is a term used among practical mechanics to denote the rectilinear motion of a piston rod, &c. in the direction of its length: and contrivances by which such alternate rectilinear motions are converted into rotatory ones, and *vice versa*, in pumps, steam-engines, saw-mills, &c. are usually called contrivances for parallel motions.

In motions of this kind it is generally thought a desirable thing to give the piston-rod, the saw, or the like, a uniform velocity through the whole of its progress; then to bring it at once to rest, again to give it instantaneously a finite velocity in the opposite direction, and so on. But this seems impossible in nature; all changes of motion *which we observe* are gradual, because all impelling bodies have some elasticity or softness by which they yield to compression: and in the way in which pistons are commonly moved, *viz.* by cranks or something analogous to them, the motion is *very sensibly* gradual. Hence, it may be observed that most attempts to correct these inequalities in motion are misplaced; and if they could be accomplished would greatly injure the pump or other machine. One of the best methods of producing this effect is to make the piston-rod consist of two parallel bars, having teeth in the sides which front each other. Let a toothed wheel be placed between them, having only the half of its circumference furnished with teeth. It is evident, without any further description, that if this wheel be turned uniformly round its axis, the piston-rod will be moved uniformly up and down without intermission. This has often been put in practice, and the piston-rod made to work between grooved rollers; but the machine always went by jolts, and seldom lasted a few days. Unskilled mechanists attributed this to defect in the execution: but the fault is essential, and lies in the principle. The machine could not perform one stroke if the first mover did not slacken a little, or the different parts of the machine did not yield by bending, or by compression; and no strength of materials could withstand the violence of the strains at every reciprocation of the motion. This is chiefly experienced in great works which are put in motion by a water-wheel, or some other equal power exerted on the mass of matter of which the machine consists. The water-wheel being of great weight moves with considerable steadiness or uniformity; and when an additional resistance is opposed to it by the beginning of a new stroke of the piston, its great quantity of motion is but

little affected by this addition, and it proceeds very little retarded; and the machine must either yield a little by bending and compression, or go to pieces, which is the common event. Cranks are free from this inconvenience, because they accelerate the piston gradually, and bring it gradually to rest, while the water-wheel moves round with almost perfect uniformity. The only inconvenience (and it may be considerable) attending this slow motion of a piston at the beginning of its stroke is, that the valves do not shut with rapidity, so that some water gets back through them. But when they are properly formed and loaded, this is but trifling.

It would seem, then, that those contrivances in which the piston-rod communicates the rotatory motion by means of a crank, or something similar in its effect, are most fit to be adopted in practice; and that the attempts of mechanists in this point of view may in all probability be properly restrained to the methods of keeping the piston-rod, &c. from deviating to any side, during its alternate motion. Two or three of the best methods of performing this, with which we are acquainted, are the following.

1. Let a fixed circular ring whose diameter is equal to the stroke of the piston have teeth all round the interior part of its circumference; and let a smaller wheel, whose diameter is only half that of the ring, have equal teeth on the exterior part of its rim, to play into the teeth of the ring: let the axis of the wheel to which the rotatory motion is to be communicated pass through the centre of the larger ring; and let a moveable bar join the centre of this ring to that of the smaller wheel. Then, if the upper extremity of the piston-rod be attached to a pin fixed on the rim of the inner wheel, at the place where the two wheels are in contact in their lowest point, and the rod be put into motion, it will cause the small wheel to revolve upon the inner part of the fixed ring, and by this means give the proposed rotatory motion to the axis passing through the centre of the ring. At the same time the extremity of the piston-rod will be confined to move in the vertical diameter of the ring: because it is made to describe an epicycloid of that kind which is formed by a circle rolling along the inside of another circle of double diameter; in which case, it is well known, the epicycloid becomes a diameter of the larger circle, and the smaller circle makes two complete revolutions while it is moving from any one point of the larger circle to the same point again.

This contrivance was devised, we believe, by Mr. White, an Anglo-American. It is almost unnecessary to observe that the converse is equally applicable in the conversion of a rotatory into a parallel motion.

2. Another method is represented in figure 10. pl. XXIII. where the piston-rod is kept from deviation. A is the cylinder, B the piston, C the piston-rod, D the crank, and E the connecting rod of the crank and piston-rod. When the piston is at *e*, the crank is at *a*; when the piston is at B, the crank is either at *g* or *b*; and when the piston is at *g*, the crank is at *f*: so that when the motion of the crank is uniform that of the piston is variable. The rod H equal in length to the crank D moves about the centre F, and is joined to one end of the rod I, to the other end of which is connected the socket L that receives the top end of the piston-rod. A certain point *m* is taken at pleasure in the rod I, to carry a short axle for the rods K, which are broken in the figure to show the socket L. To find the centre of motion of the rods K, move the end L of the rod I up and down in the vertical line *cfa*, and mark three positions *n*, *m*, *r*, of the point *m* on that rod: describe a circle to pass through those three points; its radius will be equal to the length of the rods K, and its centre will be the point where those rods must be fixed to a bolt or axle in the framing. This contrivance causes the top of the piston-rod to move from P by L to O, and back again by L to *p*; and the dotted lines show the position of the several rods at the extremities of the motion.

In fig. 11. pl. XXIII. we have given a horizontal section, to show the connexion of H, I, K, &c. pointing out in what way I grasps L, and E both. The inequality of the piston's motion will be reduced by making the connecting rod E as long as circumstances will permit.

If the rod I were extended to the left of the point *p*, the same kind of apparatus would become a lever with a moveable fulcrum, by means of which a weight might be raised in a vertical line from P to O; or a pump piston-rod worked without deviation.

This construction is described in a porismatic form, by Professor Playfair, in his Outlines of Nat. Philosophy, vol. i. art. 355. See also pl. XXXIX. fig. 9ª D.

3. A third method is exhibited in fig. 8. pl. XXIII. where there are three rods A, B, and C, besides the connecting rod D. The rods A and C are of equal lengths, and the connecting rod is attached to the middle point of the rod B. The guides A, and C, are fixed at their ends E, and F, by bolts to the framing. Thus the point B, to which is fixed the top of the piston-rod, is made to move in the right line *b*B*b*′; and the dotted lines show the positions of the rods at the extremities of the stroke. Fig. 7. shows in what way the piston-rod P and connecting rod D might be joined to the guides B and C.

This method and the preceding were devised by Mr. William Dryden: a mechanic whose ingenuity needs not our encomium.

4. Another method is shown in fig. 12. pl. XXIII. A and B are two bolts in the framing at equal distances on opposite sides of the vertical line in which the piston is to move. AC, BD, two bars of equal length, each equal to about half the distance AB. CL, DL, two other equal bars, rather more than double the length of the former, moving freely on joints at C and D. At L is a socket, as in fig. 10. to receive the top of the piston-rod, and to which the bars CL, DL, and the connecting rod E, are attached. By this contrivance it is obvious, that as the rods BC, BD, turn upon the centres A, B, in contrary directions, the piston-rod will be made to move in the right line PM without deviation; NM being the length of the stroke. The relative lengths of the bars AC, CL, may be varied at pleasure: but those we have mentioned will be found as well as any in practice.

5. A piston-rod may also be kept from deviating to either side, while it gives motion to a crank, and *vice versa*, thus: place a cross-bar at a distance from the end of the cylinder rather greater than the stroke of the piston, and make the piston-rod play in a hole made in this cross-bar; let an axle be fixed to a proper point of the piston-rod between the end of the cylinder and the cross-bar, and from this axle let two equal connecting rods pass to the crank, one on each side the cross-bar: by this simple contrivance the alternating and circular motions may be communicated to the different parts of the machine with great facility.

6. A rectilinear vertical motion may, again, be produced thus. Two of the adjacent angles of a parallelogram are made to describe concentric circles, so that the side between them passes through their centre, and one of the remaining angles describes another circle having its convexity opposed to that of the two former, then the fourth angle of the parallelogram will describe a line that differs insensibly from a straight line. This construction is the invention of Mr. Watt, and now very common.

PARCIEUX'S AREOMETER. See Vol. I. art. 401, 409.

PATERNOSTER-WORK. See HYDRAULIC *Engines*. No. 5.

PENDULUM, in mechanics, any heavy body, so suspended as that it may swing backwards and forwards, about some fixed point, by the force of gravity.

These alternate ascents and descents of the pendulum are called its oscillations, or vibrations; each complete oscillation being the descent from the highest point on one side down to the lowest point of the arch, and so on up to the highest point

on the other side. The point round which the pendulum moves or vibrates is called its centre of motion, or point of suspension; and a right line drawn through the centre of motion, parallel to the horizon, and perpendicular to the plane in which the pendulum moves, is called the axis of oscillation. There is also a certain point within every pendulum into which, if all the matter that composes the pendulum were collected, or condensed as into a point, the times in which the vibrations would be performed would not be altered by such condensation; and this point is called the centre of oscillation. The length of the pendulum is always estimated by the distance of this point below the centre of motion, being usually near the bottom of the pendulum; but in a slender cylinder, or any other uniform prism or rod suspended at the top, it is at the distance of one-third from the bottom, or two-thirds below the centre of motion.

The length of a pendulum, so measured to its centre of oscillation that it will perform each vibration in a second of time, thence called the second's pendulum, has, in the latitude of London, been generally taken at $39\frac{2}{10}$ or $39\frac{1}{5}$ inches; but by some very ingenious and accurate experiments, the late celebrated Mr. George Graham found the true length to be $39\frac{128}{1000}$ inches, or $39\frac{1}{8}$ inches very nearly.

The length of the pendulum vibrating seconds at Paris was found by Varin, Des Hays, De Glos, and Godin, to be $440\frac{5}{6}$ lines; by Picard $440\frac{1}{2}$ lines; and by Mairan $440\frac{17}{30}$ lines.

In our first volume (book II. ch. ii.), where the theory of pendulums was laid down, we remarked that the length of the second pendulum was different in different parts of the earth. It would not be easy to exhibit a completely accurate theorem for the length of the pendulum at all places on the earth's surface: but besides what is exhibited in art. 286, vol. I., the best and most simple with which we are acquainted was first given by Mr. *Krafft* in the new Petersburgh Memoirs, vol. vii. It is this: if x be the length of a pendulum that swings seconds in any given latitude l, and in a temperature of 10 degrees of Reaumur's thermometer, then will the length of that pendulum, for that latitude, be thus expressed, viz.

$$x = (439{\cdot}178 + 2{\cdot}321 \sin^2 l) \text{ lines of a French foot.}$$

And this expression agrees very nearly, not only with all the experiments made on the pendulum in Russia, but also with those of Mr. Graham, and those of Mr. Lyons in 79° 50′ north latitude, where he found its length to be 241·38 lines: nor does it differ more from the recent experiments than may be fairly imputed to the effects of irregular density near the earth's surface.

Since metals expand by heat and contract by cold, pendu-

lums, which are constituted chiefly of metal, must be subject to variations in consequence of such expansion and contraction; and various are the contrivances which have been devised to correct the errors in the estimates of time which have been thus produced: a few of these will here be described.

The vulgar method of remedying the inconvenience arising from the extension and contraction of the rods of common pendulums is by applying the bob, or small ball, with a screw, at the lower end; by which means the pendulum is at any time made longer or shorter, as the ball is screwed downwards or upwards; and thus the time of its vibration is kept continually the same.

The *gridiron* PENDULUM was the invention of Mr. John Harrison, a very ingenious artist, and celebrated for his invention of the watch for finding the difference of longitude at sea, about the year 1725; and of several other time-keepers and watches since that time: for all which he received the parliamentary reward of between 20 and 30 thousand pounds. It consists of 5 rods of steel, and 4 of brass, placed in an alternate order; the middle rod being of steel, by which the pendulum ball is suspended: these rods of brass and steel, thus placed in an alternate order, and so connected with each other at their ends, that while the expansion of the steel rods has a tendency to lengthen the pendulum, the expansion of the brass rods, acting upwards, tends to shorten it. And thus, when the lengths of the brass and steel rods are duly proportioned, their expansions and contractions will exactly balance and correct each other, and so preserve the pendulum invariably of the same length. The simplicity of this ingenious contrivance is much in its favour; and the difficulty of adjustment seems the only objection to it.

Mr. Harrison, in his first machine for measuring time at sea, applied this combination of wires of brass and steel, to prevent any alterations by heat or cold; and in the machines or clocks he has made for this purpose, a like method of guarding against the irregularities arising from this cause is used.

The principal objections to this mode of compensation are, 1st. The difficulty of exactly adjusting the lengths of the rods. 2dly. Of proportioning their thickness, so that they shall all begin to expand or contract at the same instant. 3dly. The connecting bars of a pendulum thus constructed are apt to move by starts. 4thly. This kind of pendulum is more exposed to the air's resistance than a simple pendulum.

Another excellent contrivance for the same purpose is described by M. Thiout, a French author on clock-making. It

was used in the north of England by an ingenious artist about 60 years ago. This invention is as follows: a bar of the same metal with the rod of the pendulum, and of the same dimensions, is placed against the back part of the clock-case: from the top of this a part projects, to which the upper part of the pendulum is connected by two fine pliable chains or silken strings, which just below pass between two plates of brass, whose lower edges will always terminate the length of the pendulum at the upper end. These plates are supported on a pedestal fixed to the back of the case. The bar rests upon an immoveable base at the lower part of the case, and is inserted into a groove; by which means it is always retained in the same position. From this construction, it is evident that the extension or contraction of this bar, and of the rod of the pendulum, will be equal, and in contrary directions. For, suppose the rod of the pendulum to be expanded any given quantity by heat; then, as the lower end of the bar rests upon a fixed point, the bar will be expanded upwards, and raise the upper end of the pendulum just as much as its length was increased; and hence its length below the plates will be the same as before.

In Voigt's Magazin fuer den nevesten Zustande de Naturkunde, vol. iv. are described the gridiron pendulums of Mr. Benzenberg, which are composed of *lead* and *iron*. Mr. B. was induced to employ lead on account of its great dilatability, which is to iron as 2·57 to 1, so that 16·5 inches of lead compensate 1·3 of iron; and he chose iron in preference to steel, because easier to work. The compensation was made by a single rod in the centre, 16½ inches long, French measure, and half an inch thick. It was simply pinned into gorges in the cross-piece of copper; but the other parts of the gridiron were riveted in the usual way. The iron rods were made of the best thick iron wire.

The materials of this pendulum are cheap, and it may be made in a couple of days. As the pressure takes place in a vertical direction, there is no danger, according to Mr. B., of rods of these dimensions bending.

To correct the compensation, the central rod of lead must be left so long that we may be sure the compensation is in excess. The quantity of error may then be found by the freezing apparatus, and how much it is requisite to cut from the rod may be calculated with the greatest exactness.

The *mercurial* PENDULUM was the invention of the ingenious Mr. Graham, in consequence of several experiments relating to the materials of which pendulums might be formed, in 1715. Its rod is made of brass, and branched towards its lower end, so as to embrace a cylindric glass vessel 13 or 14 inches long, and about 2 inches diameter; which being filled about 12

inches deep with mercury, forms the weight or ball of the pendulum. If upon trial the expansion of the rod be found too great for that of the mercury, more mercury must be poured into the vessel: if the expansion of the mercury exceeds that of the rod, so as to occasion the clock to go fast with heat, some mercury must be taken out of the vessel, so as to shorten the column. And thus may the expansion and contraction of the quicksilver in the glass be made exactly to balance the expansion and contraction of the pendulum rod, so as to preserve the distance of the centre of oscillation from the point of suspension invariably the same.

Mr Graham made a clock of this sort, and compared it with one of the best of the common sort, for three years together; when he found the errors of his but about one eighth part of those of the latter. Philos. Trans. No. 392.

The only defect we have ever heard ascribed to this pendulum, is that the expansion of the mercury commences sooner than that of the rod; but, after all, there are many strong proofs of its practical excellence. Mr. F. Baily has recently recommended the mercurial pendulum, and greatly improved its construction, in an elaborate paper published in vol. I. of the *Transactions of the Astronomical Society of London.*

The *lever* PENDULUM. From all that appears concerning this construction of a pendulum, we are inclined to believe that the idea of making the difference of the expansion of different metals operate by means of a lever originated with Mr. Graham, who in the year 1737 constructed a pendulum, having its rod composed of one bar of steel between two of brass, which acted upon the short end of a lever, to the other end of which the ball or weight of the pendulum was suspended.

This pendulum however was, upon trial, found to move by jerks; and therefore laid aside by the inventor, to make way for the mercurial pendulum, just mentioned.

Mr. Short informs us in the Philos. Trans. vol. 47, art. 88, that a Mr. Fotheringham, a quaker in Lincolnshire, caused a pendulum of this kind to be made: it consisted of two bars, one of brass, and the other of steel, fastened together by screws, with levers to raise or let down the bulb; above which these levers were placed. M. Cassini too, in the History of the Royal Academy of Sciences at Paris, for 1741, describes two sorts of pendulums for clocks, compounded of bars of brass and steel; and in which he applies a lever to raise or let down the bulb of the pendulum, by the expansion or contraction of the bar of brass.

Mr. John Ellicott also, in the year 1738, constructed a pendulum on the same principle, but differing from Mr. Graham's in many particulars. The rod of Mr. Ellicott's pendulum was

composed of two bars only; the one of brass and the other of steel. It had two levers, each sustaining its half of the ball or weight; with a spring under the lower part of the ball to relieve the levers from a considerable part of its weight, and so to render their motion more smooth and easy. The one lever in Mr. Graham's construction was above the ball: whereas both the levers in Mr. Ellicott's were within the ball; and each lever had an adjusting screw, to lengthen or shorten the lever, so as to render the adjustment the more perfect. See the Philos. Trans. vol. 47, p. 479; where Mr. Ellicott's methods of construction are described, and illustrated by figures.

Notwithstanding the great ingenuity displayed by these eminent artists on this construction, it must further be observed, in the history of improvements of this nature, that Mr. Cumming, another eminent artist, has given, in his Essays on the Principles of Clock and Watch-work, Lond. 1766, an ample description, with plates, of a construction of a pendulum with levers, in which it seems he has united the properties of Mr. Graham's and Mr. Ellicott's, without being liable to any of the defects of either. The rod of this pendulum is composed of one flat bar of brass, and two of steel: he uses three levers within the ball of the pendulum; and, among many other ingenious contrivances, for the more accurate adjusting of this pendulum to mean time, it is provided with a small ball and screw below the principal ball or weight, one entire revolution of which on its screw will only alter the rate of the clock's going one second per day; and its circumference is divided into 30, one of which divisions will therefore alter its rate of going one second in a month.

Mr. Edward Troughton has lately invented a *tubular* pendulum, which acts on the principle of the gridiron pendulum: in this construction the apparent rod is a tube of brass reaching from the bob nearly to the top; this contains another tube and five wires in its belly, so disposed as to produce altogether (like the nine-bar gridiron of Harrison) three expansions of steel downwards, and two of brass upwards; whose lengths being inversely proportioned to their dilatation, when properly combined, destroy the whole effect that either metal would have singly. The small visible part of the rod near the top is a brass tube, whose use is to cover the upper end of the middle wire, which is single, and otherwise unsupported. Drawings of this pendulum may be seen in Nicholson's Journal, No. 36. N S.

For another ingenious compensation pendulum of steel and zinc, by Mr. Adam Reid, we refer to the article PENDULUM in the PANTOLOGIA, and to my *Mathematics for Practical Men.*

After all, so long as the vibration of pendulums is performed

in a medium of varying density, we must not look for an accurate time-piece for ascertaining the longitude, &c.; unless a self-correcting mercurial pendulum could be contrived, adapted to counteract the smallest variations effected by the ambient air. The errors of a time-piece are but half corrected by the fabrication of pendulums adapted to obviate the expansion of metals by increase of temperature, if the works themselves still remain constructed of such expansible materials. A correct time-piece, therefore, will be that of which not only the works and pendulum are constructed of the least expansible materials, but the pendulum itself shall vibrate in a medium of unalterable density; a desideratum only to be obtained by causing the vibrations to be performed *in vacuo*, or by a self-correcting pendulum, as above alluded to. Mr. G. J. Wright, of Kennington, who has some observations on this subject in Tilloch's Philosophical Magazine, No. 57. says the best substance to compose the works of a correct time-keeper is ivory, or the horn of the narwhal or sea unicorn (which is almost entirely composed of enamel); especially if any means were known of increasing its hardness so as to vie with the metals.

The most general remedy against the chief inconveniences of pendulums, is to make them *long*, to vibrate in *small* arcs, and to have the bobs as ponderous as is consistent with the structure of the machine. In those cases where it is wished to increase the time of vibration without increasing the length of the pendulum, recourse may be had to the *angular* pendulum, the theory of which has been given in art. 311, vol. I.; or to the pendulum formed of a slender cylinder with a ball at each end, and a contrivance for a moveable centre of motion, as already explained in the same article of the first volume. Akin to this is the contrivance described by M. Prony, at p. 229, *Connaissance des Tems pour l'an* 1817.

Hydraulic PENDULUM, a simple contrivance by which the rectilinear motion of flowing water is made to communicate an alternating motion.

The hydraulic pendulum of Perrault (pl. XXXVIII. fig. 4A and supp. B) is a chest or cask ABCD moveable on two pivots *m*, and divided into two parts by the partition CD. When the bottom AB of this vessel is horizontal, the water from the source M falls on C the middle of the partition. Immediately it becomes inclined, the water falls into the part, such as B, elevated above the horizon; this part of the vessel increases in weight in proportion as it fills with water; when it is full the entire vessel turns on its axis, and the water from the source falls in the part AC of the vessel, which in consequence filling up, the weight causes it to oscillate: this oscillatory motion

will be common to a pendulum bar, or to any other body attached to the double vessel.

In the hydraulic pendulum of M. Boitias (pl. XXXVIII. fig. 4 E), there is placed at the inferior extremity of a pendulum a very large float-board, moveable on pivots which turn on the parallel branches of a frame fixed to the pendulum. This float-board will assume alternately the vertical and the horizontal position. In the first it plunges into the stream and receives the impulsion of the water; the float-board moves with the pendulum, and having reached the lowest point of its oscillation, a counterweight causes it to turn on its pivot and gives it the horizontal position: then the pendulum, the weight of which is no longer counterbalanced by the action of the water, takes as well as the float-board the horizontal position, and commences a new oscillation. Instead of employing a counterweight to open and shut the float-board, there may be employed two cords attached to fixed points and to the float-board; these threads stretched by the pendulum will draw the float-board at the beginning and end of the oscillation, and cause it to assume successively its horizontal and vertical positions. The hydraulic pendulum does not, like the common pendulum, oscillate on both sides of the vertical, but simply on one. It moves on towards that side to which it is impelled by the motion of the water, till, reaching the highest point of its oscillation, the float-board opens, and the whole is brought back by its own weight to the vertical position; in that position the float-board again closes the frame, and the impulsion of the water upon it causes it to oscillate again. And so on.

PENSTOCK is a sluice or floodgate, serving to retain or let go at pleasure the water of a mill-pond. The following is a description of a pentrough and stock for equalising the water falling on water-wheels, by George Quayle, esq.

To insure a regular supply of water on the wheel, and to obviate the inconveniences arising from the usual mode of delivering it from the bottom of the pentrough, this method is devised of regulating the quantity delivered by a float, and taking the whole of the water from the surface.

Section of the pentrough. (Plate XVI. fig. 4.) A, the entrance of the water. B, the float, having a circular aperture in the centre: in which is suspended C, a cylinder, running down in the case E below the bottom of the pentrough. This is made water tight at the bottom of the pentrough at F, by a leather collar placed between two plates, and screwed down to the bottom.

The cylinder is secured to the float so as to follow its rise and fall; and the water is admitted into it through the opening in

its sides, and there, passing through the box or case E, rises and issues at G on the wheel. By this means, a uniform quantity of water is obtained at G; which quantity can be increased or diminished by the assistance of a small rack and pinion attached to the cylinder, which will raise or depress the cylinder above or under the water line of the float; and, by raising it up to the top, it stops the water entirely, and answers the purpose of the common shuttle. This pinion is turned by the handle H, similar to a winch-handle; and is secured from running down by a ratchet-wheel at the opposite end of the pinion axis.

K and L are two upright rods to preserve the perpendicular rise and sinking of the float, running through the float, and secured at the top by brackets from the sides.

M, a board let down across the pentrough nearly to the bottom, to prevent the horizontal impulse of the water from disturbing the float.

Fig. 5. A transverse section, showing the mode of fixing the rack and pinion, and their supports, on the float. The rack is inserted into a piece of metal running across the cylinder near the top. That the water may pass more freely when nearly exhausted, the bottom of the cylinder is not a plane, but is cut away so as to leave two feet, as at C, fig. 4. The float is also kept from lying on the pentrough bottom by four small feet; so that the water gets under it regularly from the first.

Fig. 6. An enlarged view of the cylinder, showing the rack and ratchet-wheel, with the click, and one of the openings on the side of the cylinder: the winch or handle being on the opposite side, and the pinion, by which the rack is raised, inclosed in a box between them. (Transactions of the Society of Arts, vol. XI. A.D. 1793.)

PERSIAN-WHEEL. See HYDRAULIC *Engines*. No. 4.

PILE-ENGINE, a machine by which piles are driven into the earth for the foundations of piers and other structures.

In pile-engines the contrivance consists in drawing up a great weight, called a ram or hammer, to a moderate height, and then letting it fall freely with a considerable momentum upon the head of the pile. In the most simple pile engines the ram is drawn up by men pulling at a cord running over a fixed pulley, and suffering the cord to slip from their hands when the weight is sufficiently elevated. Among more complex engines, the best we have seen are those invented by Mr. Vauloue and by Mr. S. Bunce.

Description of Vauloue's pile-engine. (See pl. XXII.) A is a great upright shaft or axle, on which are the great wheel B and the drum C, turned by horses joined to the bars S, S. The wheel B turns the trundle X, on the top of whose axis is

the fly O, which serves to regulate the motion, as well as to act against the horses, and to keep them from falling when the heavy ram Q is discharged to drive the pile P down into the mud in the bottom of the river. The drum C is loose upon the shaft A, but is locked to the wheel B by the bolt Y. On this drum the great rope HH is wound; one end of the rope being fixed to the drum and the other to the follower G, to which it is conveyed by the pulleys I and K. In the follower G is contained the tongs F, that take hold of the ram Q by the staple R for drawing it up. D is a spiral or fusee fixed to the drum, on which is wound the small rope T that goes over the pulley U, under the pulley V, and is fastened to the top of the frame at 7. To the pulley-block V is hung the counterpoise W, which hinders the follower G from accelerating as it goes down to take hold of the ram; for as the follower tends to acquire velocity in its descent, the line T winds downwards upon the fusee on a larger and larger radius, by which means the counterpoise W acts stronger and stronger against it; and so allows it to come down with only a moderate and uniform velocity. The bolt Y locks the drum to the great wheel, being pushed upward by the smaller lever 2, which goes through a mortise in the shaft A, turns upon a pin in the bar 3, fixed to the great wheel B, and has a weight 4, which always tends to push up the bolt Y through the wheel into the drum. L is the great lever turning on the axis *m*, and resting upon the forcing bar 5, 5, which goes through a hollow in the shaft A, and bears up the little lever 2.

By the horses going round, the great rope H is wound about the drum C, and the ram Q is drawn up by the tongs F in the follower G, until the tongs come between the inclined planes E; which by shutting the tongs at the top, opens it at the foot, and discharges the ram, which falls down between the guides *bb* upon the pile, P, and drives it by a few strokes as far into the mud as it will go; after which, the top part is sawed off close to the mud by an engine for that purpose. Immediately after the ram is discharged, the piece 6 upon the follower G takes hold of the ropes *aa*, which raise the end of the lever L, and causes its end N to descend and press down the forcing bar 5 upon the little lever 2, which by pulling down the bolt Y, unlocks the drum C from the great wheel B; and then, the follower being at liberty, comes down by its own weight to the ram; and the lower ends of the tongs slip over the staple R, and the weight of their heads causes them to fall outward and shut upon it. Then the weight 4 pushes up the bolt Y into the drum, which locks it to the great wheel, and so the ram is drawn up as before.

As the follower comes down, it causes the drum to turn backward, and unwinds the rope from it, whilst the horses, great wheel, trundle, and fly, go on with an uninterrupted motion; and as the drum is turned backward, the counterpoise W is drawn up, and its rope T wound upon the spiral fusee D.

There are several holes in the under side of the drum, and the bolt Y always takes the first of them that it finds, when the drum stops by the falling of the follower upon the ram; until which stoppage the bolt has not time to slip into any of the holes.

The peculiar advantages of this engine are, that the weight called the ram, or hammer, may be raised with the least force; that, when it is raised to a proper height, it readily disengages itself and falls with the utmost freedom; that the forceps or tongs are lowered down speedily, and instantly of themselves again lay hold of the ram and lift it up.

This engine was placed upon a barge on the water, and so was easily conveyed to any place desired. The ram was a ton weight; and the guides *bb*, by which it was let fall, were 30 feet high.

Description of Bunce's Pile-engine.

Fig. 1 and 2. plate XXII. represent a side and front section of the machine. The chief parts are, A, fig. 1. which are two endless ropes or chains, connected by cross pieces of iron, B (fig. 2). corresponding with two cross grooves cut diametrically opposite in the wheel C (fig. 1.), into which they are received; and by which means the rope or chain A is carried round. FHK is a side-view of a strong wooden frame moveable on the axis H. D is a wheel, over which the chain passes and turns within at the top of the frame. It moves occasionally from F to G upon the centre H, and is kept in the position F by the weight I fixed to the end K. In fig. 3. L is the iron ram, which is connected with the cross pieces by the hook M. N is a cylindrical piece of wood suspended at the hook at O, which, by sliding freely up the bar that connects the hook to the ram, always brings the hook upright upon the chain when at the bottom of the machine, in the position of GP. See fig. 1.

When the man at S turns the usual crane-work, the ram being connected to the chain and passing between the guides, is drawn up in a perpendicular direction; and when it is near the top of the machine, the projecting bar Q of the hook strikes against a cross piece of wood at R (fig. 1.), and consequently discharges the ram; while the weight I of the moveable frame instantly draws the upper wheel into the position shown at F, and keeps the chain free of the ram in its descent. The hook, while descending, is prevented from catching the chain by the wooden

piece N: for that piece being specifically lighter than the iron weight below, and moving with a less degree of velocity, cannot come into contact with the iron till it is at the bottom and the ram stops. It then falls, and again connects the hook with the chain, which draws up the ram as before.

In this machine, as well as Vauloue's, the motion of the first wheel is uninterrupted, so that very little time is lost in the operation: with a slight alteration it might be made to work with horses. It has the advantage over Vauloue's engine in point of simplicity; it may be originally constructed at less expense, and is not so liable to be deranged. Both, however, are ingenious performances, and part of their construction might be advantageously introduced into other machines.

PIPES, for conveying of water, for pumps, water-engines, &c. are usually of lead, iron, earth, or wood: the latter are usually made of oak or elder. Those of iron are cast in forges; their usual length is from six to eight feet: several of these are commonly fastened together by means of four screws at each end, with leather or old hat between them, to stop the water. Those of earth are made by the potters; these are fitted into one another, one end being always made wider than the other. To join them the closer and prevent their breaking, they are covered with tow and pitch: their length is usually about that of the iron pipes. The wooden pipes are trees bored with large iron augers of different sizes, beginning with a less, and then proceeding with a larger successively; the first being pointed, the rest being formed like spoons, increasing in diameter from one to six inches or more: the pipes are fitted into the extremities of each other (as represented in pl. XXII. fig. 1.), and are sold by the foot.

Wooden pipes are bored either by a borer advancing horizontally while the wood to be pierced is turned round, in some such manner as in boring of ordnance; or, by causing the timber to be gradually advanced, while the borer turns round: the latter method is the most common. The apparatus most frequently adopted, when the first mover is a stream of water, is that invented by M. Morel, and described by Belidor (Architecture Hydraulique, tom. I.) This machinery is represented at pl. XXII. fig. 1. where the vertical wheel A is put into motion by water descending upon it through a trough or sloping canal: upon the horizontal axle of this wheel is a cog-wheel B, which gives motion to the lanterns C, D, the common axis of these lanterns being in a vertical position. The lantern D turns at the same time two cog-wheels E and F: the first, E, which is vertical, turns the auger that bores the wood: and the second, F, which is horizontal, has attached to it by a pin which

is at a small distance from its centre, a lever or arm H, with a hook at its end, taking into the indentations of one of the wheels of the carriage that carries the wood to be bored. Another lever, I, hanging upon the former, is prevented from falling by a spring, and pushes by its extremity against the notches of the lower end of the same wheel. Thus, as the cog-wheel turns round, the carriage-wheel is first pulled forward by the hook and lever H, and then pushed backward as far by the arm I; by this means causing a pinion upon the axle of the carriage-wheel to advance the rackwork above it, together with the timber to be bored: so that the timber is advanced by a slight reciprocating motion of the carriage. The auger, being generally some feet in length, plays in holes in two pieces L, L, which retain it in its horizontal position; and thus it forms a cylindrical cavity in the wood, as required.

For an account of the ingenious method of boring *stone* pipes employed at the Fox-Hill Quarry, in Gloucestershire, see the article PIPE in the PANTOLOGIA.

PLANET WHEELS are wheels by whose mutual connexion a variable angular motion, such as that of the radius vector of a planet in its orbit, may be exhibited. The common contrivance now in use for this purpose was invented, we think, by Desaguliers: it consists of two elliptical wheels connected either by teeth running into each other, or by a band; these wheels revolve on their foci, and while the driving ellipses move uniformly, the radius vector of the other has the required motion.

A much older, and at the same time *far better*, method than that of Desaguliers, is described in the first volume of the Recueil des Machines et Inventions approuvées par l'Acad. Roy. des Sci. 1699: it was the invention of M. *Joli de Dijon.* The following account of this method is translated from the work just mentioned.

If it be desired to move a wheel of 24 teeth by a pinion of 6, in such a manner that in some parts of its revolution it shall move as swiftly as if it had but twelve teeth, and in other parts as slowly as if it had 48 teeth, the method of accomplishing this is as follows:

1. Describe the rectangle LMNO (fig. 1. pl. XXIII.) having its side NO equal to the radii of the great wheel and the pinion taken together, and its breadth LN equal to their thickness; which last must be greater the more considerable the inequality of the proposed movement. Let NO be so divided in Q, that QO may be to QN as 6 to 48, that is to say, reciprocally as the velocity of the pinion to the greatest velocity of the wheel. Also divide LM in P in the proportion of 6 to 12, or reciprocally as the velocity of the pinion to the least velocity of the wheel.

Then join PQ, and draw as many lines SR parallel to LM, as there are intended to be teeth in the great wheels; upon which write the degrees of velocity they express, which are in the inverse ratio of their lengths.

2. Let two truncated cones be formed in the lathe; one equal to that which would be formed by the revolution of the trapezoid LPQN about LN as an axis; and the other equal to what would be formed by the revolution of the trapezoid PQMO about the axis MO. On the largest of these two cones let the circles generated by the revolution of the points P, T, Q, be marked and distinguished by the same numeral figures as the corresponding parallels of the rectangle LO. Upon the two bases of the conic frustum describe radial lines, which shall make angles at the centre (fig. 3.) in the same proportion to each other as the intended velocities of the wheel, as expressed in fig. 2. and let teeth be cut in the curve surface of the cone corresponding with these lines: after this, look on the circles that express the different velocities, and have been traced on the same surface, to find what part of each tooth ought to remain opposite its corresponding radius, and cut or file the rest away. Thus will the teeth lie in an oblique or elliptical curve on the conical surface, as is exhibited in the figure by a darker shade. The pinion must be made of a regular conic shape, as is shown at MO in fig. 3.

By this contrivance the largest or widest teeth will always meet the largest part of the pinion, and the narrowest will correspond with the smallest part: on which account, though the motion of the pinion be uniform, the wheel will be carried unequably, according to the assigned law.

In a similar manner may planet-wheels be described to exhibit any other proposed variation.

PRESS, a machine of wood, or iron, serving to squeeze any body very close.

Presses usually consist of six pieces: two flat smooth planks, between which the things to be pressed are laid; two screws or worms fastened to the lower plank, and passing through two holes in the upper; and two nuts in form of an S, that serve to drive the upper plank, which is moveable, against the lower, which is fixed. See BRAMAH'S *Machine.*

PRESSES *used for expressing Liquors* are in most respects the same with the common presses, only the underplank is perforated with a great number of holes for the juice to run through. Others have only one screw, or arbor, passing through the middle of the moveable plank, which descends into a kind of square box full of holes, through which the juices flow as the arbor is turned.

Press *used by Joiners* to keep close the pannels, &c. of wainscot, consists of two screws, and two pieces of wood, four or five inches square, and two or three feet long, whereof the holes at two ends serve for nuts to the screws.

Founders' press, is a strong square frame, consisting of four pieces of wood firmly joined together with tenons, &c. It is of various sizes: two of them are required to each mould at the two extremes whereof they are placed; so as that, by driving wooden wedges between the mould and sides of the press, the two parts of the mould for the metal may be pressed close together.

Press, *binders' cutting-*, is a machine used equally by book-binders, stationers, and pasteboard-makers; consisting of two large pieces of wood in form of cheeks, connected by two strong wooden screws; which, being turned by an iron bar, draw together, or set asunder, the cheeks, as much as is necessary for the putting in the books or paper to be cut. The cheeks are placed lengthwise on a wooden stand in form of a chest, into which the cuttings fall. Aside of the cheeks are two pieces of wood of the same length with the screws, serving to direct the cheeks, and prevent their opening unequally. Upon the cheeks the plough moves, to which the cutting-knife is fastened by a screw; which has its key, to dismount it, on occasion, to be sharpened.

The plough consists of several parts; among the rest, a wooden screw or worm, which, catching within the nuts of the two feet that sustain it on the cheeks, brings the knife to the book or paper which is fastened in the press between two boards. This screw, which is pretty long, has two directories, which resemble those of the screws of the press. To make the plough slide square and even on the cheeks, so that the knife may make an equal paring, that foot of the plough where the knife is not fixed slides in a kind of groove, fastened along one of the cheeks. Lastly, the knife is a piece of steel, six or seven inches long, flat, thin, and sharp, terminating at one end in a point, like that of a sword, and at the other in a square form, which serves to fasten it to the plough.

As the long knives used by us in the cutting of books or papers are apt to jump in the cutting thick books, the Dutch are said to use circular knives with an edge all round; which not only cut more steadily, but last longer without grinding.

Various other presses are used in different arts and manufactures; but it does not seem necessary to give particular descriptions of any others, except the press used in printing of books, and the rolling press used in copper-plate printing.

The common printing-*press* represented in pl. XXIII. is

a curious and rather complex machine. The body consists of two strong cheeks, *a*, *a*, standing perpendicularly, and joined together by four cross pieces; the cap *b*, and the head *c*, which is moveable, being partly sustained by two iron pins or long screw-bolts that pass the cap; the till or shelf *dd*, by which the spindle and its apparatus are kept in their proper position; and the winter *e*, which bears the carriage, and sustains the effort of the press beneath. The spindle *f* is an upright piece of iron pointed with steel, having a male screw, which goes into the female one in the head about four inches. Through the eye *g* of this spindle is fastened the bar *k*, by which the pressman makes the impression. The spindle passes through a hole in the middle of the till; and its point works into a brass pan, or nut, supplied with oil, which is fixed to an iron plate let into the top of the platen. The body of the spindle is sustained in the centre of an open frame of polished iron, 1, 1, 2, 2, 3, 3, fixed to it in such a manner as, without obstructing its free play, to keep it in a steady direction; and at the same time to serve for suspending the platen. This frame consists of two parts: the upper called the *garter*, 1, 1; the under called the *crane*, 2, 2. These are connected together by two short legs or bolts, 3, 3; which being fixed below in the two ends of the crane, pass upward through two holes in the till, and are received at top into two eyes at the ends of the garter, where they are secured by screws. The carriage *ll* is placed a foot below the platen, having its fore part supported by a prop called the *fore-stay*, while the other rests on the winter. On this carriage, which sustains the plank, are nailed two long iron bars or ribs; and on the plank are nailed short pieces of iron or steel called *cramp-irons*, equally tempered with the ribs, and which slide upon them when the plank is turned in or out. Under the carriage is fixed a long piece of iron called the *spit*, with a double wheel in the middle, round which leather girts are fastened, nailed to each end of the plank: and to the outside of the spit is fixed a rounce *m*, or handle, to turn round the wheel. Upon the plank is a square frame or coffin, in which is inclosed a polished stone, on which the form *n* is laid; at the end of the coffin are three frames, viz. the two tympans and the frisket: the tympans *o* are square, and made of three slips of very thin wood, and at the top a piece of iron still thinner; that called *the outer tympan* is fastened with hinges to the coffin: they are both covered with parchment; and between the two are placed blankets, which are necessary to take off the impression of the letters upon the paper. The frisket P is a square frame of thin iron, fastened with hinges to the tympan: it is covered with paper cut in the necessary places, that the sheet, which is put between the frisket and the

great or outward tympan, may receive the ink, and that nothing may hurt the margins. To regulate the margins, a sheet of paper is fastened upon this tympan, which is called the *tympan sheet*; and on each side is fixed an iron point, which makes two holes in the sheet, which is to be placed on the same points when the impression is to be made on the other side. In preparing the press for working, the parchment which covers the outer tympan is wetted till it is very soft, in order to render the impression more equable; the blankets are then put in, and secured from slipping by the inner tympan: then, while one pressman is beating the letter with the balls covered with ink taken from the ink block, the other person places a sheet of white paper on the tympan sheet; turns down the frisket upon it, to keep the paper clean and prevent its slipping; then, bringing the tympans upon the form, and turning the rounce, he brings the form with the stone, &c. weighing about 300 lbs. weight, under the platen; pulls with the bar, by which means the platen presses the blankets and paper close upon the letter, whereby half the form is printed; then easing the bar, he draws the form still forward; gives a second pull, and letting go the bar, turns back the form, takes up the tympans and frisket, takes out the printed sheet, and lays on a fresh one; and this is repeated till he has taken off the impression upon the full number of sheets the edition is to consist of. One side of the sheet being thus printed, the form for the other is laid upon the press, and worked off in the same manner.

For a minute description of the several parts of a common press, of the various implements employed in printing, and of Lord Stanhope's improved press, the reader is referred to Mr. Stower's valuable work, "The Printer's Grammar."

We must here say a little respecting the recent improvements in printing; though we have not room to present more than a very general account. For some time the "*Times*" newspaper has been *entirely* printed by machinery; that is to say, the forms, or pages, being composed and made up, in the usual manner, have been worked off by means of machinery, moved by a steam engine, instead of being printed at the common press. The paper, since this change in the mode of working, has not only been as well printed, but much better than before. The number that can be worked in one hour is stated at 1100.

It is somewhat remarkable, that while this invention, which has taken a long time to perfect it, has been in progress, another, for the same object, was also carrying on by Mr. Bacon, of Norwich, and Mr. Donkin (engineer) of Bermondsey, which was set to work within a day after the former. Mr. Bacon has

published a prospectus of the latter machine, to which is added the following notice:—"Since this prospectus was printed, the machine has been set to work on a French Testament in this city, for the British and Foreign Bible Society. It is worked by one man and two boys; and we may venture to affirm, that, in the ordinary manner in which the London newspapers are printed, many more copies than the number stated by the *Times* could be taken off with the greatest ease. Dr. Milner, the Master of Queen's College, Mr. Wood, President of St. John's, and Mr. Kaye, since Master of Christ's, as a deputation from the Syndics of the Press at Cambridge, have also inspected the machine, and have manifested, by their readiness to contract with the Patentees for its introduction at the University, all the zeal which might be expected in that body for the cause of literature and of the art.—These are the earliest patrons of the machine."

As we cannot convey to our readers a full description of either of these machines, we must content ourselves with briefly stating their general principles. In that of the *Times*, the forms are laid upon a travelling carriage, as in the common press, but having a range of such length that the form, by passing under a system of rollers, receives a charge of ink, and still going on, receives from another roller the sheet pressed down upon it, by passing under the roller: when through, the sheet is taken off; the form receives another charge of ink from rollers, and, on its return presents another sheet, which has, in the interim, been placed on the paper roller—and so alternately, in *going* and *returning*, a sheet is printed.—In Messrs. Bacon and Donkin's machine, there is no reciprocating motion. The types are placed on a *prism* of as many sides as the nature of the form requires. This *prism* occupies the centre of an upright frame, like the rollers in a copperplate-press: below this is a kind of compound-faced roller, suited to the form of the *prism*: between these, the sheets to be printed (attached to the face of a piece of cloth) are passed in succession; and, in the mean time, the revolution of the type-prism brings its different portions in succession under a system of inking-rollers placed over it, by which it receives charges of ink, to be delivered to the sheets as they pass in succession between the lower rollers.

The press of the *Times* has cost the proprietors upwards of eight thousand pounds—a sum, however, speedily refunded by the savings that arise from the invention, as it allows the discharge of pressmen on that establishment whose wages amounted to £25 a week; while the number of compositors may be also much reduced, by its obviating the necessity for a duplicate of the types of the inner form, which the more

respectable daily prints have of late years found necessary. It was first stated in the *Times* that the apparatus multiplied copies at the rate of 1100 per hour: it will produce them now with much greater speed, and with astonishing clearness and beauty. The invention is protected by a patent; but itself is its best protector. The apparatus requires a great space, and is very complicated; the plan of the old printing-press is scarcely brought to mind by that of the new one: the carriage and something like its ribs are the only parts that have any likeness to Caxton's or Stanhope's machinery. The ink is communicated to the types by several rollers, under which the form passes in its progress towards a cylinder of about three feet diameter, on which the sheets of paper are successively laid: so that something of the principle of the copperplate-press is in this new apparatus extended to the letter-press. The ink is distributed on the rollers with so much accuracy, that the terms "*monks*" and "*friars*" will in a few years be unknown in printing. Some inconvenience from "*picks*" remains to be prevented. Confident expectations are entertained that the apparatus will be in a short time so simplified, as to bring the expense of it within the means of all respectable printers.

As this invention has raised great expectations, we insert extracts from a letter published by Mr. Koenig on this subject; it shows, also, the state of the Continent, and suggests one cause of British superiority, in whatever operations depend on ingenuity and industry.

"The first idea relating to this invention occurred to me eleven years ago, and the first experiments were made soon after in Saxony. My original plan was confined to an improved press, in which the operation of laying the ink on the types was to be performed by an apparatus connected with the motion of the coffin, in such a manner that one hand could be saved. As nothing could be gained in expedition by this plan, the idea soon suggested itself to move this press by machinery, or to reduce the several operations to one rotatory motion, to which any first mover might be applied. Its execution was not completed, when I found myself under the necessity of seeking assistance for the further prosecution of it.

"There is on the Continent no sort of encouragement for an enterprise of this description. The system of Patents, as it exists in England, being either unknown, or not adopted in the continental states, there is no inducement for *individual enterprise*, and projectors are commonly obliged to offer their discoveries to some Government, and to solicit encouragement. I need hardly add, that scarcely ever is an invention brought to maturity under such circumstances. The well-known fact,

that almost every invention seeks, as it were, refuge in England, and is there brought to perfection, where the Government does not afford any other protection to inventors than what is derived from the wisdom of the laws, seems to indicate that the Continent has yet to learn from her the best manner of encouraging the mechanical arts. I had my full share in the ordinary disappointments of continental projectors; and after having lost in Germany and Russia upwards of two years in fruitless applications, I arrived about eight years ago in England, where I was introduced to and soon joined by Mr. Thomas Bensley, a printer so well known to the literary world, that the mention of his name is sufficient.

"The execution of the plan was begun, and as the experiments became very expensive, two other gentlemen, Mr. George Woodfall, and Mr. Richard Taylor, eminent printers in London, joined us.

"After many obstructions and delays, the first printing machine was completed exactly on the plan which I have described in the specification of my first patent, dated March 29, 1810. It was set to work in April 1811. The sheet (H) of the new Annual Register for 1810, "Principal Occurrences," 3000 copies, was printed with it, and is, I have no doubt, the first part of a book ever printed with a machine.

"The actual use of it, however, soon suggested new ideas, and led to the rendering it less complicated and more powerful. Impressions produced by means of cylinders, which had likewise been already attempted by others without the desired effect were again tried by me upon a new plan, namely, to place the sheet round the cylinder, thereby making it, as it were, part of its periphery. After some promising experiments, the plan for a new machine on this principle was made, and a manufactory established for the purpose. Since this time I have had the benefit of my friend Mr. Bauer's assistance, who, by the judgment and precision with which he executed my plans, has greatly contributed to their success. The new machine was completed in December, 1812, after great difficulties attending the cylindrical impression. Sheets G and X of Clarkson's Life of Penn, vol. 1, are the first printed with an entirely cylindrical press. The papers of the Protestant Union were also printed with it in February and March, 1813. Sheet M of Aiton's Hortus Kewensis, vol. V. will show the progress of improvement in the use of this machine. All together there are about 160,000 sheets now in the hands of the public, printed with this machine, which, with the aid of two hands, takes off 800 in the hour. It is accurately described in the specifications of my two patents, dated Oct. 30, 1812, and July 23, 1813.

"The machines now printing the *Times* and *Evening Mail* are on the same principle as that just mentioned; but they have been contrived for the particular purpose of a newspaper of extensive circulation, where *expedition* is the great object.

"The first introduction of the invention was considered by some as a difficult and even hazardous step. The proprietor of the *Times* having made that his task, the public are aware that it is in good hands.

"Fr. Koenig."

Since the last edition of this work was published, the construction of printing machinery has been still farther improved. We cannot here enter into all the minutiæ; but our engraving of *Bensley's Printing Machine*, given upon pl. XLIII, exhibits of itself a tolerably intelligible view of its nature, and of the process of printing through its instrumentality.

A boy is represented as laying on

A the sheet of white paper.

B the Cylinder which prints the first side of the paper.

C intermediate Cylinders over which the paper travels to

D the Cylinder which gives the final impression.

E the Inking Rollers under which the Form (i. e. the types) is in the act of passing.

F the Reservoir of Ink, from which the Inking Rollers are supplied.

G the Form, receiving its last inking before it goes under the Printing Cylinder.

H a sheet is seen just being delivered into the hands of another Boy, whose business it is to keep the sheets, as they come out, in a *heap*.

The *lines* at top of the machine represent the Tapes, which run round the Cylinders and secure the sheet.

Lithographic Printing-PRESS. The process of *lithography* has now attained so much eminence, that it will not be uninteresting to our readers to meet with a description of the press and rollers used, according to the best construction, and the manner of printing. See pl. XLIII, where

Fig. 4. Is a side elevation of the press, with the scraper partly down.

5. A cross section through the middle.

6. A horizontal plan of the upper part.

7. Detail of the manner in which the scraper is held down during the impression.

8. End elevation of the press.

9. To explain the manner in which the centre of motion of the scraper is raised and lowered.

The press consists of a strong frame, having on the upper

part a platten, or bed, *a*, to receive the stone, and which is moved along grooves in the upper part of the frame by means of a star-wheel, *b*, to the axle of which is fixed a cylinder, *c*. On this cylinder the straps *d*, *d*, are gathered, which work over the pulleys, *e*, fixed to the bed.

When the stone is placed on the bed, and ready for the impression, the frisket, or cover, *f*, of the bed is brought down from the position marked by the dotted outline in fig. 4, and shut over the stone, as shown in the same figure. This cover consists of a strong piece of calf's skin, stretched by screws with nuts and hooks, which catch hold of an iron rod sewed along one end of the skin. The other end of it is fixed to the opposite end of the frame (see fig. 6). The cover is fixed to the bed by hinges, *g*, which can be screwed at different heights, according to the thickness of the stones. When the cover is opened, it rests against the frame *h*, which can be adjusted to different heights. (See figs. 4 and 8.)

The cross piece *i* having the scraper *k* fixed in it, is now brought down, and the catches *l* lock into the upper of the piece *n* sliding between the grooved upright *m*. This is shown more in detail in fig. 4; the upper part, where the catches lock, is of iron, and has a joint and handle to pull it out when the scraper is to be unlocked. A spring, *o*, keeps it generally in an upright position, to be ready to hold the catches *l*, *l*.

When the scraper is locked down, the printer sets his foot on the treadle *p* of the lever, which presses the scraper with great power on the stone. The pressure is by a double lever, having a connecting rod, *q*, which can be adjusted so as to bring the upper arm *r* nearer to the treadle, when an increase of pressure is required, or a thinner stone is placed on the bed, which makes it necessary to bring the scraper lower down. The arm *r* passes through an iron frame on the sliding piece *n*, and thus brings it down when the treadle is depressed. The hook *s* holds down the treadle during the impression.

The star-wheel *b* is now turned round, and by this motion the bed is drawn under the scraper, and the impression is taken. The bed passes over a roller *t*, which is placed with its centre directly under the scraper (see fig. 5).

As the stones are not always of the same thickness, the scraper must be brought to different heights. Fig. 9 shows an adjusting screw for the purpose of regulating the end farthest from the catches, there being a sliding piece between the grooved uprights *u*, in which the centre is fixed, on which the cross piece *i* turns. The iron *v*, fig. 5, stops the cross piece and scraper from falling back.

When the bed has been drawn out, the printer releases the

treadle, which is raised up by the balance weight *w*, and the scraper being unlocked and thrown back, the bed is drawn to its first position by the weight *x*.

As the surface of the stone is not always quite parallel to the bed, a simple contrivance has been adopted to allow a self adjustment of the scraper, which is allowed to turn on the centre, and pressed down by a spring acting on each end, but yielding if necessary at either. It is shown by the dotted lines in fig. 5. The screw *y*, presses the scraper lower, or raises it, if required.

The scrapers are made of beech wood.

The Roller.—The roller for inking the drawing is of the form represented in the plate, fig. 10. The length may vary, but it ought to be full four inches in diameter. It is covered with flannel, rolled tightly three or four times round, and nailed at the ends. It is then covered with a stretched calf-skin, fitting quite tight. The seam must be made neatly with the bootmaker's closing stitch. The ends of the leather are gathered with a string, and tied round the projecting ends of the roller. Loose handles, A, A, made of thick leather, are put on these ends when it is used. The leather must be put on the roller with the rough side outwards.

Printing Ink.—The printing ink is composed as other printing inks are, of oil, varnish, and very fine lamp-black, well mixed together. To prepare the varnish, a saucepan is about half filled with pure linseed oil, and heated over a fire, till it ignites from the flame of a piece of burning paper. It should then be allowed to burn till it is reduced to the degree required; and if during the operation, there appears danger of its boiling over, it must be immediately taken off the fire, and the cover, which ought to fit quite close on the saucepan, must be put on to extinguish the flame. This is to prevent accidents; and the operator cannot be sufficiently cautioned against the danger attending the burning of the varnish, which ought never to be performed in a room with a boarded floor, or indeed in any part of a house. Wet sacks are the best things to put out the flame in case of accident.

Several inks must be prepared, differing in the degree of viscidity, or thickness of the varnish from which they are made, and the quantity of black mixed with them. The longer the oil is burned, the thicker the varnish becomes.

The thinnest varnish is burned till it has lost nearly one-fourth of its volume.

The next till it is reduced one-third.

The thickest till it is reduced one-half.

These directions are to be considered as very general ones; and the state of the varnish is best judged of during the burn-

ing, by taking out some with a spoon, and letting a drop fall on a cold earthenware plate, and trying its degree of viscidity with the finger. The thinnest sort should be like common honey, the other should draw out in strings, which will be longer as the varnish is thicker. The thickest will draw out in strings two or three feet long.

It is quite essential to have the oil pure, and the saucepan perfectly clean, and to keep the varnish in clean close jars in a cool place.

It is best not to make the varnish long before it is wanted; for if any decomposition takes place in it, the drawing will be spoiled by the printing ink.

The black is mixed with the varnish on a grinding stone with a muller, in small successive quantities; care being taken that the first portion of black is equally mixed with the varnish before a second is added. In the thickest inks this requires considerable labour.

By mixing the varnishes together, any degree of stiffness of the ink may be obtained; and, by putting more or less black, its thickness is regulated.

The printer must always have by him several small pots, each containing a different printing ink, to be used as occasion requires. A small quantity, not more than the size of a hazel-nut should be used at a time, for it is desirable to charge the roller with as small a quantity as possible. It must be worked well on the colour table with the roller in all directions, that it may be equally distributed all over the roller.

Ink drawings are generally printed with a stiffer ink than chalk drawings.

Preparation of the Stone for Printing.—The drawing being finished on the stone as before described, is sent to the Lithographic printer, on whose knowledge of his art the success of the impressions entirely depends. The first process is to etch the drawing, as it is called. This is done by placing the stone obliquely on one edge over a trough, and pouring over it very dilute nitric acid. It is poured on the upper part of the stone, and runs down all over the surface. The stone is then turned, and placed on the opposite edge, and the etching water, being collected from the trough, is again poured over it in the same manner. The degree of strength, which is little more than one *per cent.* of acid, should be such as to produce a very slight effervescence; after the etching water has lain on the stone for a second or two, its strength must vary according to the heat of the atmosphere, and the degree of fineness of the drawing. It is desirable to pass the etching water two or three times over the darkest parts of the drawing, as they require more etching

than the lighter tints. Some stones also, and different chalks, require different degrees of strength of the acid, and experience alone can guide the Lithographer in his practice on this point. Chalk drawings require weaker acid than the ink.

The stone is now carefully washed, by pouring clean rain water over it, and afterwards with gum-water; and, when not too wet, the roller, charged with printing-ink, is rolled over it in both directions—sideways, and from top to bottom, till the drawing takes the ink. It is then well covered over with a solution of gum-arabic in water, of about the consistency of oil. This is allowed to dry, and preserves the drawing from any alteration, as the lines cannot spread, in consequence of the pores of the stone being filled with the gum. After the etching, it is desirable to leave the stone for a day, and best not to leave it more than a week, before it is printed from. In some establishments a few proofs are taken immediately after the drawing is etched, but it is better not to do so. (*Glasgow Mech. Mag.*)

The *Rolling*-PRESS, as it has been commonly used in copper-plate printing, is represented in fig. 3. pl. XV. This machine, like the common press, may be divided into two parts, the *body* and *carriage*, analogous to those in the other.

The body consists of two cheeks PP of different dimensions, ordinarily about four feet and a half high, a foot thick, and two and a half apart, joined at top and bottom by cross pieces. The cheeks are placed perpendicularly on a wooden stand or foot, LM, horizontally placed, and sustaining the whole press. From the foot likewise rise four other perpendicular pieces, *c*, *c*, *c*, *c*, joined by other cross or horizontal ones *d*, *d*, *d*, which may be considered as the carriage of the press, as serving to sustain a smooth, even plank, HIK, about four feet and a half long, two feet and a half broad, and an inch and a half thick: upon which the engraven plate is to be placed. Into the cheeks go two wooden cylinders or rollers DE, FG, about six inches in diameter, borne up at each end by the cheeks, whose ends, which are lessened to about two inches diameter, and called *trunnions*, turn in the cheeks between two pieces of wood, in form of half-moons, lined with polished iron, to facilitate the motion. The space in the half-moons, left vacant by the trunnion, is filled with paper, pasteboard, &c. that they may be raised and lowered at discretion; so as only to leave the space between them necessary for the passage of the plank charged with the plate, paper, and blankets. Lastly, to one of the trunnions of the upper roller is fastened a cross, consisting of two levers AB, or pieces of wood traversing each other. The arms of this cross serve in lieu of the handle of the common press; giving a motion to

the upper roller, and that to the under one; by which means the plank is protruded, or passed between them.

The practice of printing from copper-plates is nearly as follows. The workmen take a small quantity of the ink on a rubber made of linen rags, strongly bound about each other, and with this smear the whole face of the plate as it lies on a grate over a charcoal fire. The plate being sufficiently inked, they first wipe it over with a foul rag, then with the palm of their left hand, and then with that of the right; and to dry the hand and forward the wiping, they rub it from time to time in whiting. The address of the workman consists in wiping the plate perfectly clean, without taking the ink out of the engraving. The plate thus prepared is laid on the plank of the press; over the plate is laid the paper, first well moistened, to receive the impression; and over the paper two or three folds of flannel. Things being thus disposed, the arms of the cross are pulled, and by that means the plate with its furniture is passed through between the rollers, which pinching very strongly, yet equally, presses the moistened paper into the strokes of the engraving whence it takes out the ink, and receives the required impression.

PRESSURE ENGINES for raising water by the pressure and descent of a column inclosed in a pipe, have been lately erected in different parts of this country. The principle now adverted to was adopted in some machinery executed in France about 1731 (see Belidor de Arch. Hydraul. lib. iv. ch. 1.), and was likewise adopted in Cornwall about sixty years ago. But the pressure engine of which we are about to give a particular description is the invention of Mr. R. Trevithick, who probably was not aware that any thing at all similar had been attempted before. This engine, a section of which, on a scale of a quarter of an inch to a foot, is shewn in pl. XXIII. was erected about 20 years ago at the Druid Copper Mine, in the parish of Illogan, near Truro. AB represents a pipe six inches in diameter, through which water descends from the head to the place of its delivery to run off by an adit at s, through a fall of 34 fathoms in the whole; that is to say, in a close pipe down the slope of a hill 200 fathoms long, with 26 fathoms fall; then perpendicularly six fathoms, till it arrives at B, and thence through the engine from B to S two fathoms. At the turn B the water enters into a chamber C, the lower part of which terminates in two brass cylinders four inches in diameter; in which two plugs or pistons of lead, D and E, are capable of moving up and down by their piston rods, which pass through a close packing above, and are attached to the extremities of a chain leading over and properly attached to the wheel G, so that it cannot slip.

The leaden pieces D and E are cast in their places, and have no packing whatever. They move very easily; and if at any time they should become loose, they may be spread out by a few blows with a proper instrument, without taking them out of their place. On the sides of the two brass cylinders, in which D and E move, there are square holes communicating towards F and G, which is an horizontal trunk or square pipe, four inches wide and three inches deep. All the other pipes G, G, and R, are six inches in diameter, except the principal cylinder wherein the piston H moves; and this cylinder is ten inches in diameter, and admits a nine-feet stroke, though it is here delineated as if the stroke were only three feet.

The piston-rod works through a stuffing box above, and is attached to MN, which is the pit-rod, or a perpendicular piece divided into two, so as to allow its alternate motion up and down and leave a space between, without touching the fixed apparatus, or great cylinder. The pit-rod is prolonged down into the mine, where it is employed to work the pumps, or if the engine were applied to mill-work, or any other use, this rod would form the communication of the first mover.

KL is a tumbler or tumbling-bob, capable of being moved on the gudgeons V, from its present position to another, in which the weight L shall hang over with the same inclination on the opposite side of the perpendicular, and consequently the end K will then be as much elevated as it is now depressed.

The pipe RS has its lower end immersed in a cistern, by which means it delivers its water without the possibility of the external air introducing itself; so that it constitutes a torricellian column or water barometer, and renders the whole column from A to S effectual: as we shall see in our view of the operation.

The operation. Let us suppose the lower bar KV of the tumbler to be horizontal, and the rod PO so situated, as that the plugs or leaden pistons D and E shall lie opposite to each other, and stop the water-ways G and F. In this state of the engine, though each of these pistons is pressed by a force equivalent to more than a thousand pounds, they will remain motionless, because these actions being contrary to each other, they are constantly in equilibrio. The great piston H being here shown as at the bottom of its cylinder, the tumbler is to be thrown by hand into the position here delineated. Its action upon OP, and consequently upon the wheel Q, draws up the plug D, and depresses E, so that the water-way G becomes open from AB, and that of F to the pipe R: the water consequently descends from A to C; thence to GGG, until it acts beneath the piston H. This pressure raises the piston, and if there be any water above the piston, it causes it to rise and pass through F into R. During the

rise of the piston (which carries the pit-rod MN along with it), a sliding block of wood I, fixed to this rod, is brought into contact with the tail K of the tumbler, and raises it to the horizontal position, beyond which it oversets by the acquired motion of the weight L.

The mere rise of the piston, if there were no additional motion in the tumbler, would only bring the two plugs D and E to the position of rest, namely, to close G and F, and then the engine would stop; but the fall of the tumbler carries the plug D downwards quite clear of the hole F, and the other plug E upwards, quite clear of the hole G. These motions require no consumption of power, because the plugs are in equilibrio, as was just observed.

In this new situation the column AB no longer communicates with G, but acts through F upon the upper part of the piston H, and depresses it; while the contents of the great cylinder beneath that piston are driven out through GGG, and pass through the opening at E into R. It may be observed, that the column which acts against the piston is assisted by the pressure of the atmosphere, rendered active by the column of water hanging in R, to which that assisting pressure is equivalent, as has already been noticed.

When the piston has descended through a certain length, the slide or block at T, upon the pit-rod, applies against the tail K of the tumbler, which it depresses, and again oversets; producing once more the position of the plugs DE, here delineated, and the consequent ascent of the great piston H, as before described. The ascent produces its former effect on the tumbler and plugs; and in this manner it is evident that the alternations will go on without limit: or until the manager shall think fit to place the tumbler and plugs DE in the positions of rest; namely, so as to stop the passages F and G.

The length of the stroke may be varied by altering the positions of the pieces T and I, which will shorten the stroke the nearer they are together; as in that case they will sooner alternate upon the tail K.

As the sudden stoppage of the descent of the column AB, at the instant when the two plugs were both in the water-way, might jar and shake the apparatus, those plugs are made half an inch shorter than the depth of the side holes; so that in that case the water can escape directly through both the small cylinders to R. This gives a moment of time for the generation of the contrary motion in the piston and the water in GGG, and greatly deadens the concussion which might else be produced.

Some former attempts to make pressure engines upon the principle of the steam-engine have failed; because water, not

being elastic, could not be made to carry the piston onwards a little, so as completely to shut one set of valves and open another. In the present judicious construction, the tumbler performs the office of the expansive force of steam at the end of the stroke.

Mr. Boswell suggests, as a considerable improvement, that the action of this engine should be made elastic by the addition of an air-chamber, on the same principle as that used in fire-engines; this, he thinks, might be best effected by making the piston hollow, with a small orifice in the bottom, and of a larger size, to serve for this purpose, as the spring of the air would then act both on the upward and downward pressure of the water. (*Nich. Jour.* N. S. vols. i. ii.)

PULLEY, one of the simple machines, or as they are commonly called, *mechanical powers;* its theory is laid down in arts. 148—151, 267, &c. of our first volume. The present article is introduced for the purpose of mentioning some ingenious practical combinations of pulleys, in addition to those exhibited in pl. VI. vol. i.

The usual methods of arranging pulleys in their blocks may be reduced to two. The first consists in placing them one by the side of another upon the same pin: the other in placing them directly under one another upon separate pins. Each of these methods however is liable to inconvenience; and Mr. Smeaton, to avoid the impediments to which these combinations are subject, proposes to combine these two methods in one.

A very considerable improvement in the construction of pulleys has been made by Mr. James White, who obtained a patent for his invention, of which he gives the following description. Fig. 6. pl. XIX. shows the machine, consisting of two pulleys Q and R, one fixed and the other moveable. Each of these has six concentric grooves capable of having a line put round them, and thus acting like as many different pulleys, having diameters equal to those of the grooves. Supposing then each of the grooves to be a distinct pulley, and that all their diameters were equal, it is evident that if the weight 144 were to be raised by pulling at S till the pulleys touch each other, the first pulley must receive the length of line as many times as there are parts of the line hanging between it and the lower pulley. In the present case there are 12 lines *b*, *d*, *f*, &c. hanging between the two pulleys, formed by its revolution about the six upper and lower grooves. Hence, as much line must pass over the uppermost pulley as is equal to twelve times the distance of the two. But, from an inspection of the figure, it is plain that the second pulley cannot receive the full quantity of line by as much as is equal to the distance betwixt it and the

first. In like manner, the third pulley receives less than the first by as much as is the distance between the first and third; and so on to the last, which receives only one-twelfth of the whole. For this receives its share of line *n* from a fixed point in the upper frame, which gives it nothing; while all the others in the same frame receive the line partly by turning to meet it, and partly by the line coming to meet them.

Supposing now these pulleys to be equal in size, and to move freely as the line determines them, it appears evident, from the nature of the system, that the number of their revolutions, and consequently their velocities, must be in proportion to the number of suspending parts that are between the fixed point above mentioned, and each pulley respectively. Thus the outermost pulley would go twelve times round in the time that the pulley under which the part *n* of the line, if equal to it, would revolve only once; and the intermediate times and velocities would be a series of arithmetical proportionals, of which, if the first number were 1, the last would always be equal to the whole number of terms. Since then the revolutions of equal and distinct pulleys are measured by their velocities, and that it is possible to find any proportion of velocity on a single body running on a centre, viz. by finding proportionate distances from that centre; it follows, that if the diameters of certain grooves in the same substance be exactly adapted to the above series (the line itself being supposed inelastic, and of no magnitude), the necessity of using several pulleys in each frame will be obviated, and with that some of the inconveniences, to which the use of the pulley is liable.

In the figure referred to, the coils of rope by which the weight is supported are represented by the lines *a*, *b*, *c*, &c.: *a* is the line of traction, commonly called the fall, which passes over and under the proper grooves, until it is fastened to the upper frame just above *n*. In practice, however, the grooves are not arithmetical proportionals, nor can they be so; for the diameter of the rope employed must in all cases be deducted from each term; without which the smaller grooves, to which the said diameter bears a larger proportion than to the larger ones, will tend to rise and fall faster than they, and thus introduce worse defects than those which they were intended to obviate.

The principal advantage of this kind of pulley is, that it destroys lateral friction, and that kind of shaking motion which is so inconvenient in the common pulley. And lest (says Mr. White) this circumstance should give the idea of weakness, I would observe, that to have pins for the pulleys to run on is not the only nor perhaps the best method; but that I sometimes

use centres fixed to the pulleys, and revolving on a very short bearing in the side of the frame, by which strength is increased, and friction very much diminished; for to the last moment the motion of the pulley is perfectly circular: and this very circumstance is the cause of its not wearing out in the centre as soon as it would, assisted by the ever-increasing irregularities of a gullied bearing. These pulleys, when well executed, apply to jacks, and other machines of that nature, with peculiar advantage, both as to the time of going and their own durability; and it is possible to produce a system of pulleys of this kind of six or eight parts only, and adapted to the pocket, which, by means of a skein of sewing silk, or a clue of common thread, will raise upwards of a hundred weight.

The friction of the pulley is now reduced to almost nothing by Mr. Garnett's ingenious patent friction-rollers, which produce a great saving of labour and expense, as well as in the wear of the machine, both when applied to pulleys and to the axles of wheel-carriages. His general principle is this: between the axle and nave, or centre pin and box, a hollow space is left, to be filled up by solid equal rollers nearly touching each other. These are furnished with axles inserted into a circular ring at each end, by which their relative distances are preserved; and they are kept parallel by means of wires fastened to the rings between the rollers, and which are riveted to them.

PUMP, a hydraulic machine for raising water by the pressure of the atmosphere.

The most important and certain part of the theory of pumps has been laid down in arts. 524—538, of our first volume; and the construction of two or three kinds has been already described in this volume under the articles CENTRIFUGAL *machine*, FIRE *engine*, FORCER, and HYDRAULIC *engines*. A few other useful, yet not complex, pumps, will be described in the present article: and some account will be added of the most ingenious pistons and valves.

1. A modification of the sucking-pump, which has been much recommended, is exhibited in plate XXV. fig. 17. Here the suction-pipe CO comes up through a cistern KMNL deeper or longer than the intended stroke of the piston, and has a valve C at top. The piston, or what acts in lieu of it, is a tube AHGB, open at both ends, and of a diameter somewhat larger than that of the suction-pipe. The interval between them is filled up at HG by a ring or belt of soft leather, which is fastened to the outer tube, and moves up and down with it, sliding along the smoothly polished surface of the suction-pipe with very little friction. There is a valve I on the top of this piston, opening upwards. Water is poured into the outer cistern.

The outer cylinder or piston being drawn up from the bottom, there is a great rarefaction of the air which was between them, and the atmosphere presses the water up through the suction-pipe to a certain height; for the valve I keeps shut by the pressure of the atmosphere and its own weight. Pushing down the piston causes the air, which had expanded from the suction-pipe into the piston, to escape through the valve I: drawing it up a second time allows the atmosphere to press more water into the suction-pipe, to fill it, and also part of the piston. When this is pushed down again, the water which had come through the valve C is now forced out through the valve I into the cistern KMNL, and now the whole is full of water. When, therefore, the piston is drawn up, the water follows, and fills it, if not 33 feet above the water in the cistern; and when it is pushed down again, the water which filled the piston is all thrown out into the cistern; and after this it delivers its full contents of water every stroke. The water in the cistern KMNL effectually prevents the entrance of any air between the two pipes; so that a very moderate compression of the belt of soft leather at the mouth of the piston cylinder is sufficient to make all perfectly tight.

It might be made differently. The ring of leather might be fastened round the top of the inner cylinder at DF, and slide on the inside of the piston cylinder: but the first form is most easily executed. Muschenbroeck has given a figure of this pump in his large system of natural philosophy, and speaks very highly of its performance. But we do not see any advantage which it possesses over the common sucking-pump. He indeed says that it is without friction, and makes no mention of the ring of leather between the two cylinders. Such a pump will raise water extremely well to a small height, and it seems to have been a model only which he had examined; but if the suction-pipe be long, it will by no means do without the leather; for on drawing up the piston, the water of the upper cistern will rise between the pipes, and fill the piston, and none will come up through the suction-pipe.

We may take this opportunity of observing, that most of the ingenious contrivances of pumps without friction are of little importance in great works; because the friction which is completely sufficient to prevent all escape of water in a well-constructed pump is but a very trifling part of the whole force. In the great pumps which are used in mines, and are worked by a steam-engine, it is very usual to make the pistons and valves without any leather whatever. The working barrel is bored truly cylindrical, and the piston is made of metal of a size that will just pass along it without sticking. When this is drawn

up with the velocity competent to a properly loaded machine, the quantity of water which escapes round the piston is insignificant. The piston is made without leathers, not to avoid friction, which is also insignificant in such works; but to avoid the necessity of frequently drawing it up for repairs through such a length of pipes.

2. If a pump absolutely without friction be wanted, the following seems preferable for simplicity and performance to most that we have seen, when made use of in proper situations. Let NO (fig. 18.) be the surface of the water in the pit, and K the place of delivery. The pit must be as deep in water as from K to NO. ABCD is a wooden trunk, round or square, open at both ends, and having a valve P at the bottom. The top of this trunk must be on a level with K, and has a small cistern EADF. It also communicates laterally with a rising pipe GHK, furnished with a valve at H opening upwards. LM is a beam of timber so fitted to the trunk as to fill it without sticking, and is of at least equal length. It hangs by a chain from a working beam, and is loaded on the top with weights exceeding that of the column of water which it displaces. Now suppose this beam allowed to descend from the position in which it is drawn in the figure; the water must rise all around it in the crevice which is between it and the trunk, and also in the rising pipe; because the valve P shuts, and H opens; so that when the plunger has got to the bottom, the water will stand at the level of K. When the plunger is again drawn up to the top by the action of the moving power, the water sinks again in the trunk, but not in the rising pipe, because it is stopped by the valve H. Then allowing the plunger to descend again, the water must again rise in the trunk to the level of K, and it must now flow out at K; and the quantity discharged will be equal to the part of the beam below the surface of the pit-water, deducting the quantity which fills the small space between the beam and the trunk. This quantity may be reduced almost to nothing, for if the inside of the trunk and the outside of the beam be made tapering, the beam may be let down till they exactly fit; and as this may be done in square work, a good workman can make it exceedingly accurate. But in this case, the lower half of the beam and trunk must not taper; and this part of the trunk must be of sufficient width round the beam to allow free passage into the rising pipe. Or, which is better, the rising pipe must branch off from the bottom of the trunk. A discharge may be made from the cistern EADF, so that as little water as possible may descend along the trunk when the piston is raised.

One great excellence of this pump is, that it is perfectly free

from all the deficiencies which in common pumps result from want of being air-tight. Another is, that the quantity of water raised is precisely equal to the power expended; for any want of accuracy in the work, while it occasions a diminution of the quantity of water discharged, makes an equal diminution in the weight which is absolutely necessary for pushing down the plunger. We have seen a machine consisting of two such pumps suspended from the arms of a long beam, the upper side of which was formed into a walk with a rail on each side. A man stood on one end till it got to the bottom, and then walked gently up to the other end, the inclination being about twenty-five degrees at first, but gradually diminished as he went along, and changed the load of the beam. By these means he made the other end go to the bottom, and so on alternately, with the easiest of all exertions, and what we are most fitted for by our structure. With this machine, a very feeble old man, weighing 110 pounds, raised 7 cubic feet of water $11\frac{1}{2}$ feet high in a minute, and continued working 8 or 10 hours every day. A stout young man, weighing nearly 135 pounds, raised $8\frac{1}{3}$ to the same height; and when he carried 30 pounds, conveniently slung about him, he raised $9\frac{1}{4}$ feet to that height, working 10 hours a-day without fatiguing himself. This exceeds Desaguliers' maximum of a hogshead of water 10 feet high in a minute, in the proportion of 9 to 7 nearly. It is limited to very moderate heights; but in such situations it is very effectual. Belidor applies a nearly similar contrivance to the working of double pumps in general.

3. Another most ingenious contrivance of a pump without friction is that of Mr. Haskins, described in Phil. Trans. No. 370, and called by him the QUICKSILVER PUMP. Its construction and mode of operation are complicated; but the following preliminary observations will, we hope, render them abundantly plain.

Let there (fig. 19.) be a cylindrical iron pipe, about six feet long, open at top; also another cylinder, connected with it at bottom, and of smaller diameter. It may either be solid, or, if hollow, it must be close at top. Let a third iron cylinder, of an intermediate diameter, be made to move up and down between the other two without touching either, but with as little interval as possible. This middle cylinder communicates, by means of the pipe AB, with the upright pipe FE, having valves C and D (both opening upwards) adjoining to the pipe of communication. Suppose the outer cylinder suspended by chains from the end of a working beam, and let mercury be poured into the interval between the three cylinders till it fills the space to about three-fourths of their height. Also suppose that the lower end of the

pipe FE is immersed into a cistern of water, and that the valve D is less than 33 feet above the surface of this water.

Now suppose a perforation made somewhere in the pipe AB, and a communication made with an air-pump. When the air-pump is worked, the air contained in CE, in AB, and in the space between the inner and middle cylinders, is rarified, and is abstracted by the air-pump; for the valve D immediately shuts. The pressure of the atmosphere will cause the water to rise in the pipe CE, and will cause the mercury to rise between the inner and middle cylinders, and sink between the outer and middle cylinders. Let us suppose mercury 12 times heavier than water: then for every foot that the water rises in EC, the level between the outside and inside mercury will vary an inch; and if we suppose DE to be 30 feet, then if we can rarefy the air so as to raise the water to D, the outside mercury will be depressed to *q*, *r*, and the inside mercury will have risen to *s*, *t*, *sq* and *tr* being about 30 inches. In this state of things, the water will run over by the pipe BA, and every thing will remain nearly in this position. The columns of water and mercury balance each other, and balance the pressure of the atmosphere.

While things are in this state of equilibrium, if we allow the cylinders to descend a little, the water will rise in the pipe FE, which we may now consider as a suction-pipe; for by this motion the capacity of the whole is enlarged, and therefore the pressure of the atmosphere will still keep it full, and the situation of the mercury will again be such that all shall be in equilibrio. It will be a little lower in the inside space, and higher in the outside.

Taking this view of things, we see clearly how the water is supported by the atmosphere at a very considerable height. The apparatus is analogous to a syphon which has one leg filled with water and the other with mercury. But it was not necessary to employ an air-pump to fill it. Suppose it again empty, and all the valves shut by their own weight. Let the cylinders descend a little. The capacity of the spaces below the valve D is enlarged, and therefore the included air is rarefied, and some of the air in the pipe CE must diffuse itself into the space quitted by the inner cylinder. Therefore the atmosphere will press some water up the pipe FE, and some mercury into the inner space between the cylinders. When the cylinders are raised again, the air which came from the pipe CE would return into it again, but is prevented by the valve C.—Raising the cylinders to their former height would compress this air; it therefore lifts the valve D, and escapes. Another depression of the cylinders will have a similar effect. The water will rise

higher in FC, and the mercury in the inner space; and then after repeated strokes the water will pass the valve C, and fill the whole apparatus, as the air-pump had caused it to do before. The position of the cylinders, when things are in this situation, is represented in fig. 20. the outer and inner cylinder in their lowest position having descended about 30 inches. The mercury in the outer space stands at *q*, *r*, a little above the middle of the cylinders, and the mercury in the inner space is near the top *ts* of the inner cylinder. Now let the cylinders be drawn up. The water above the mercury cannot get back again through the valve C, which shuts by its own weight. We therefore attempt to compress it; but the mercury yields, and descends in the inner space, and rises in the outer till both are quickly on a level, about the height *vv*. If we continue to raise the cylinders, the compression forces out more mercury, and it now stands lower in the inner than in the outer space. But that there may be something to balance this inequality of the mercurial columns, the water goes through the valve D, and the equilibrium is restored when the height of the water in the pipe ED above the surface of the internal mercury is 12 times the difference of the mercurial columns (on the former supposition of specific gravity). If the quantity of water be such as to rise two feet in the pipe ED, the mercury in the outer space will be two inches higher than that in the inner space. Another depression of the cylinders will again enlarge the space within the apparatus, the mercury will take the position of fig. 19. and more water will come in. Raising the cylinders will send this water four feet up the pipe ED, and the mercury will be four inches higher in the inner than in the outer space. Repeating this operation, the water will be raised still higher in DE; and this will go on till the mercury in the outer space reaches the top of the cylinder; and this is the limit of the performance. The dimensions with which we set out will enable the machine to raise the water about 30 feet in the pipe ED; which, added to the 30 feet of CF, makes the whole height above the pit-water 60 feet. By making the cylinders longer, we increase the height of FD. This machine must be worked with great attention, and but slowly; for at the beginning of the forcing stroke the mercury very rapidly sinks in the inner space and rises in the outer, and will dash out and be lost. To prevent this as much as possible, the outer cylinder terminates in a sort of cup or dish, and the inner cylinder should be tapered at the top.

The machine is exceedingly ingenious and refined; and there is no doubt but that its performance will exceed that of any other pump which raises the water to the same height, because

friction is completely avoided, and there can be no want of tightness of the piston. But this is all its advantage; and from what has been observed, it is but trifling. The expense would be enormous; for with whatever care the cylinders are made, the interval between the inner and outer cylinders must contain a very great quantity of mercury. The middle cylinder must be made of iron plate, and must be without a seam, for the mercury would dissolve every solder. For such reasons, it has never come into general use. But it would have been unpardonable to have omitted the description of an invention which is so original and ingenious; and there are some occasions where it may be of great use, as in nice experiments for illustrating the theory of hydraulics, it would give the finest pistons for measuring the pressures of water, in pipes, &c.

4. Mr. Thomas Clark, of Edinburgh, has recently invented a *quicksilver pump* for raising water, which works almost without friction. It has great power in drawing and forcing water to any height, and is extremely simple in its construction. It is made by twisting a piece of iron tube into the form of a ring, *g q i*, (fig. 1. pl. XLIV). having the ends of the tube bent into the centre *h*, and again bent outwards, so as to form an axle to the wheel or ring thus formed. One of the ends of the axle is inserted, by means of a stuffing box at *h*, into the side of the main pipe *da*, which leads down to the well, which allows it to move easily, and at the same time keeps it air-tight. In the main pipe *da*, immediately below where the axle is inserted, or at any other convenient distance, is placed a valve *c* lifting upwards, another valve *d* lifting upwards is also placed immediately above the axle, or at any other convenient distance. There is now put into the iron ring a quantity of quicksilver, filling it from *q* to *q*, which slides backwards and forwards, as the ring is made to vibrate upon its axis in the stuffing-box at *h*, forming a vacuum in the main pipe as the silver recedes in the tube from *g* to *q*; the water rushes up from *a* to fill the vacuum, and when the silver slides back again towards *g*, the water is expelled through the upper valve *d*, and escapes at the top of the main pipe at *e*. A wheel of twelve or thirteen feet diameter will lift water the same height as a common lifting pump, and force it 150 feet higher, almost without friction.—*(Jamieson's Edinburgh Journal.)*

The following pump, without friction, may be constructed in a variety of ways by any common carpenter, without the assistance of the pump-maker, or plumber, and will be very effective for raising a great quantity of water to small heights,

as in draining marshes, marl-pits, quarries, &c. or even for the service of a house.

5. ABCD (pl. XXV. fig. 21.) is a square trunk of carpenters' work open at both ends, and having a little cistern and spout at top. Near the bottom there is a partition made of board, perforated with a hole E, and covered with a clack. *ffff* re, present a long cylindrical bag made of leather or double canvas with a fold of thin leather, such as sheepskin, between the canvas bags. This is firmly nailed to the board E with soft leather between. The upper end of this bag is fixed on a round board having a hole and valve F. This board may be turned in the lathe with a groove round its edge, and the bag fastened to it by a cord bound tight round it. The fork of the piston-rod FG is firmly fixed into this board; the bag is kept distended by a number of wooden hoops or rings of strong wire *ff*, *ff*, *ff*, &c. put into it at a few inches' distance from each other. It will be proper to connect these hoops before putting them in, by three or four cords from top to bottom, which will keep them at their proper distances. Thus will the bag have the form of a barber's bellows powder-puff. The distance between the hoops should be about twice the breadth of the rim of the wooden ring to which the upper valve and piston-rod are fixed.

Now let this trunk be immersed in the water. It is evident that if the bag be stretched from the compressed form which its own weight will give it by drawing up the piston-rod, its capacity will be enlarged, the valve F will be shut by its own weight, the air in the bag will be rarefied, and the atmosphere will press the water into the bag. When the rod is thrust down again, this water will come out by the valve F, and fill part of the trunk. A repetition of the operation will have a similar effect; the trunk will be filled, and the water will at last be discharged by the spout.

Here again is a pump without friction, and perfectly tight. For the leather between the folds of canvas renders the bag impervious both to air and water. And the canvas has very considerable strength. We know from experience that a bag of six inches diameter, made of sail-cloth No. 3. with a sheepskin between, will bear a column of 15 feet of water, and stand six hours' work per day for a month without failure, and that the pump is considerably superior in effect to a common pump of the same dimensions. We must only observe, that the length of the bag must be three times the intended length of the stroke; so that when the piston-rod is in its highest position, the angles or ridges of the bag may be pretty acute. If the bag be more stretched than this, the force which must be exerted by the labourer becomes much greater than the weight of the column

of water which he is raising. If the pump be laid aslope, which is very usual in these occasional and hasty drawings, it is necessary to make a guide for the piston-rod within the trunk, that the bag may play up and down without rubbing on the sides, which would wear it quickly out.

The experienced reader will see that this pump is very like that of Gosset and De la Deuille, described by Belidor, vol. ii. p. 120, and most writers on hydraulics. It would be still more like it, if the bag were on the under side of the partition E, and a valve placed further down the trunk. But we think that our form is greatly preferable in point of strength. When in the other situation, the column of water lifted by the piston tends to *burst* the bag, and this with a great force, as the intelligent reader well knows. But in the form recommended here, the bag is *compressed*, and the strain on each part may be made much less than that which tends to burst a bag of six inches diameter. The nearer the rings are placed to each other the smaller will the strain be.

The same bag-piston may be employed for a forcing-pump, by placing it below the partition, and inverting the valve; and it will then be equally strong, because the resistance in this case too will act by compression.

6. An ingenious variation in the construction of the sucking-pump is that with two piston-rods in the same barrel, invented by the late Mr. W. Taylor, of Southampton. A vertical section of this pump is given in fig. 1. pl. XXIV. The piston-rods have racks at their upper parts working on the opposite sides of a pinion, and kept to their proper positions by friction-rollers. The valves used in this pump are of three kinds, as shown at *a*, *b*, and *c*. The former is a spheric segment which slides up and down on the piston-rod, and is brought down by its own weight: the second, *b*, is called the pendulum-valve: and the third, *c*, is a globe which is raised by the rising water, and falls again by its own weight. Each of these valves will disengage itself from chips, sand, gravel, &c. brought up by the water. In this kind of pump the pistons may either be put in motion by a handle in the usual way, or a rope may pass round the wheel *de* in a proper groove, the two ends of which, after crossing at the lower part of the wheel, may be pulled by one man or more on each side. A pump of this kind, with a seven-inch bore, heaves a ton twenty-four feet high in a minute, with ten men, five only working at a time on each side.

7. Another improvement of the common pump has been made by Mr. Todd of Hull. This invention in some particulars bears a resemblance to the ordinary one, but he has contrived to double its powers by the following means:

Having prepared the piston-cylinder, which may be twelve feet high, he cuts from the bottom thereof about three feet; at the end of the great cylinder he places an atmospheric-valve, and to the top of the small cylinder a serving-valve. In the bottom of the small cylinder, which contains the serving-valve, is inserted an oblong elliptical curved tube, of equal calibre with the principal cylinder, and the other end is again inserted in the top of the great cylinder. This tube is divided in the same manner as the first cylinder, with atmospheric and serving valves, exactly parallel to the valves of the first cylinder. The pump, thus having double valves, produces double effects, which effects may be still further increased by extending the dimensions.

The cylinder is screwed for service on a male tube-screw, which projects from the side of a reservoir or water cistern, and is worked by hand.

The piston-plunger is worked by a toothed segment-wheel, similar to the principle of the one used in working the chain-pumps of ships belonging to the royal navy; and the wheel receives its motion from a hand-winch, which is considerably accelerated by a fly-wheel of variable dimensions, at the opposite end.

This pump, in addition to its increased powers, possesses another very great and prominent advantage. By screwing to it the long leather tube and fire-pipe of the common engine, it is in a few minutes converted into an effective fire-engine. Hence, whoever possesses one may be said to have a convenient domestic apparatus against fire. Three men can work it; one to turn the winch, another to direct the fire-pipe, and a third to supply the water.

8. Double, triple, or quadruple pumps, admit of great variety in their construction, to suit different purposes. The best collection of these with which we are acquainted is to be found in Leupold's *Theatrum Machinarum Hydraulicarum:* some in this collection are very singular and ingenious, and have particular advantages to suit local circumstances, and give them a preference. The late Mr. Benjamin Martin invented a curious and powerful pump with two pistons, the friction of which was exceedingly small. An admirable engraving of this pump, by *Lowry*, is given in vol. 20. of Tilloch's Philosophical Magazine. The triple pump, a sketch of which may be seen in fig. 9. pl. XXIV. is taken from Bockler's *Theatrum Machinarum:* the nature of the machinery by which this pump is worked will be sufficiently obvious to any person after an inspection of the figure: the horizontal wheel C, and its shaft A, are turned by the capstan bars B, this wheel drives the pinion D on the axle of

which is the equalizing fly E, and the crank F: the rotatory motion of the crank alternately raises and depresses the bar G, with the lever H turning on a roller and pivots, and thus works the pump I: at the same time the connecting rods K move in like manner the lever M, and work the pump O; and the rods K move the lever N, and work the pump P. If the levers H, M, N, are not so contrived that the extremities of each shall move through equal spaces, the bores of I, O, and P, must be made in the inverse ratio of those spaces, otherwise one or other of the reservoirs may be drawn dry; a defect that should be carefully guarded against.

9. Mr. H. W. Revely, of King Street, West Bryanstone Square, has recently proposed, in Dr. Tilloch's *Mechanic's Oracle*, an improved pump for draining, of which, as it may be very advantageously introduced in particular situations, we transcribe the account into this collection.

The principal objects in the construction of this pump are the following.

"To obtain a machine of large dimensions, and of easy transportance;

"To afford sufficient scope for the most advantageous application of the united strength of many men, in raising large bodies of water to moderate heights, as required in draining large tracts of land, sinking foundations, &c. &c.

"To prevent, as far as possible, the choking, and final destruction, of the principal parts of the machine, by the impurities with which water, under such circumstances, is always larded."

Pl. XLV. fig. 1. Front elevation of the whole machine. *a*, *a*, the frame-work, usually constructed of wood. *c*, *c*, the levers and hand-rails, by which the pumps are worked, as in the common fire-engine. *m*, *m*, two stages, or platforms, on which the men stand. *h*, *h*, the suction pipe, which branches out into two, at the upper part, in order to supply both the cylinders. This pipe is divided into short lengths by screw-joints, to suit various depths. *d*, *d*, the double rising-pipe, which communicates with the large cistern, or general receiver. *x*, *x*, the cistern, or general receiver, to which the rising-pipe, and pump cylinders, are firmly united. *f*, the delivering spout.

N. B. The same letters refer to the same parts in all the figures.

Fig. 2. A side section, showing the internal construction of the whole. *o*, the suction valve. *p*, the rising-valve. *r*, a small copper spring placed behind the rising-valve, in order to ensure its closing rapidly.

Observation.—The valves and their seats are of an oblong

rectangular form, and are made entirely of metal, without any fitting whatsoever, so that they can never be out of order.

Fig. 3. A back view, with a section of one of the cylinders. *s*, *t*, the pump-arms, with their pistons attached in the common way.

Fig. 4. A side view. *n*, *n*, the spindle, to which the working levers and pump-arms are attached. *e*, one of the cylinders, or pump-barrels, which rise a few inches above the bottom of the cistern, to a sufficient height to prevent the dirt and stones, accumulated in the latter, from falling in, but not so high as to hinder the clear water from flowing into them, and keeping their pistons free and air-tight. *g*, a man-hole, through which, when necessary, the valves may be cleaned and examined. *q*, a plug, used for the double purpose of discharging the pump of its water, and cleaning the belly-part, from time to time, of the sand and gravel which are deposited there during the working.

Fig. 5. Is a plan of the whole machine, with its levers and hand-rails ready for work.

General Observations.—It is evident from this construction, that the water which is pumped up does not pass through the cylinders; it cannot, therefore, although loaded with sand and gravel, injure them in any sensible degree. The pistons, however, are constantly working between two waters, and remain perfectly free and air-tight.

The machine, represented by this drawing, has the barrels of its pumps of the internal diameter of fourteen inches, and the length of each arm of its levers eight feet.

By placing six men outside, and four men within each hand-rail, the united strength of twenty men, acting at the extremity of a long lever, may be applied to working this pump; but in ordinary cases, where such an exertion is not requisite, half that number will be sufficient.

The quantity of water raised by this pump will vary according to the depth from which it is to be raised, and the power applied. It may be considered, however, in general, to raise from 2000 to 3000 cubic feet per hour.

10. Our attention may now be directed to some of the different forms which may be given to the *pistons* and *valves* of a pump.

The great desideratum in a piston is, that while it be as tight as possible, it should have as little friction as is consistent with this indispensable quality. The common form, when carefully executed, possesses these properties in an eminent degree. This piston is a sort of truncated cone, generally made of wood not apt to split, such as elm or beech. The small end of it is cut

off at the sides, so as to form a sort of arch, by which it is fastened to the iron rod or spear. The two ends of the conical part may be hooped with brass. This cone has its larger end surrounded with a ring or band of strong leather fastened with nails, or by a copper hoop, which is driven on it at the smaller end; the further this end reaches beyond the base of the cone, the better; and the whole must be of uniform thickness all round, so as to suffer equal compression between the cone and working barrel. The seam or joint of the two ends of this band must be made very close; but not sewed or stitched together, as that would occasion bumps or inequalities, which would spoil its tightness; and no harm can result from the want of it, because the two edges will be squeezed close together by the compression in the barrel. Nor is it by any means necessary that this compression be great: this is a very detrimental error of the pump-makers. It occasions enormous friction, and destroys the very purpose which they have in view, viz. rendering the piston air-tight: for it causes the leather to wear through very soon at the edge of the cone, and it also wears the working barrel. This very soon becomes wide in that part which is continually passed over by the piston, while the mouth remains of its original diameter, and it becomes impossible to thrust in a piston which shall completely fill the worn part. Now, a very moderate pressure is sufficient for rendering the pump perfectly tight, and a piece of glove leather would be sufficient for this purpose, if loose or detached from the solid cone; for suppose such a loose and flexible, but impervious, band of leather put round the piston, and put into the barrel; and let it even be supposed that the cone does not compress it in the smallest degree to its internal surface. Pour a little water carefully into the inside of this sort of cup or dish; it will cause it to swell out a little, and apply itself close to the barrel all round, and even adjust itself to all its inequalities. Let us suppose it to touch the barrel in a ring of an inch broad all round. We can easily compute the force with which it is pressed. It is half the weight of a ring of water an inch deep and an inch broad. This is a trifle, and the friction occasioned by it not worth regarding; yet this trifling pressure is sufficient to make the passage perfectly impervious, even by the most enormous pressure of a high column of incumbent water: for let this pressure be ever so great, the pressure by which the leather adheres to the barrel always exceeds it, because the incumbent fluid has no *preponderating* power by which it can force its way between them, and it must insinuate itself precisely so far, that its pressure on the inside of the leather shall still exceed, and only exceed, the pressure by which it endeavours to insinuate itself; and thus the piston be-

comes perfectly tight with the smallest possible friction. This reasoning is perhaps too refined for the uninstructed artist, and probably will not persuade him. To such we would recommend an examination of the pistons and valves contrived and executed by that artist, whose skill far surpasses our highest conceptions, the all-wise Creator of this world. The valves which shut up the passages of the veins, and this in places where an extravasation would be followed by instant death, are cups of thin membrane, which adhere to the sides of the channel about half way round, and are detached in the rest of their circumference. When the blood comes in the opposite direction, it pushes the membrane aside, and has a passage perfectly free. But a stagnation of motion allows the tone of the (perhaps) muscular membrane to restore it to its natural shape, and the least *motion* in the opposite direction causes it instantly to clap close to the sides of the vein, and then no pressure whatever can force a passage. We shall recur to this again when describing the various contrivances of valves, &c. What we have said is enough for supporting our directions for constructing a tight piston. But we recommend thick and strong leather, while our present reasoning seems to render thin leather preferable. If the leather be thin, and the solid piston in any part does not press it gently to the barrel, there will be in this part an unbalanced pressure of the incumbent column of water, which would instantly burst even a strong leather bag; but when the solid piston, covered with leather, exactly fills the barrel, and is even pressed a little to it, there is no such risk; and now that part of the leather band which reaches beyond the solid piston performs its office in the completest manner. We do not hesitate, therefore, to recommend this form of a piston, which is the most common and simple of all, as preferable, when well executed, to many of those more artificial, and frequently very ingenious, constructions, which we have met with in the works of the first engineers.

Belidor, an author of high reputation, has given the description of a piston which he greatly extols, and is undoubtedly a very good one, constructed from principle, and extremely well composed.

11. It consists of a hollow cylinder of metal (pl. XXV. fig. 22.) pierced with a number of holes, and having at top a flanch, whose diameter is nearly equal to that of the working barrel of the pump. This flanch has a groove round it. There is another flanch below, by which this hollow cylinder is fastened with bolts to the lower end of the piston, represented in fig. 23. This consists of a plate with a grooved edge similar to AB, and an intermediate plate which forms the seat of the valve. The

composition of this part is better understood by inspecting the figure than by any description. The piston-rod HL is fixed to the upper plate by bolts through its different branches at G, G. This metal body is then covered with a cylindrical bag of leather, fastened on it by cords bound round it, filling up the grooves in the upper and lower plates. The operation of the piston is as follows.

A little water is poured into the pump, which gets past the sides of the piston, and lodges below in the fixed valve. The piston being pushed down dips into this water, and it gets into it by the valve. But as the piston in descending compresses the air below it, this compressed air also gets into the inside of the piston, swells out the bag which surrounds it, and compresses it to the sides of the working-barrel. When the piston is drawn up again, it must remain tight, because the valve will shut and keep in the air in its most compressed state; therefore the piston must perform well during the suction. It must act equally well when pushed down again, and act as a forcer; for, however great the resistance may be, it will affect the air within the piston to the same degree, and keep the leather close applied to the barrel. There can be no doubt therefore of the piston's performing both its offices completely; but we imagine that the adhesion to the barrel will be greater than is necessary: it will extend over the whole surface of the piston, and be equally great in every part of its surface; and we suspect that the friction will therefore be very great. We have very high authority for supposing that the adhesion of a piston of the common form, carefully made, will be such as will make it perfectly tight; and it is evident that the adhesion of Belidor's piston will be much greater, and it will be productive of worse consequences. If the leather bag be worn through in any one place, the air escapes, and the piston ceases to be compressed altogether; whereas in the common piston there will very little harm result from the leather being worn through in one place, especially if it project a good way beyond the base of the cone. We still think the common piston preferable.

12. Belidor describes another forcing piston, which he had executed with success, and prefers to the common wooden forcer. It consists of a metal cylinder or cone, having a broad flanch united to it at one end, and a similar flanch which is screwed on the other end. Between these two plates are a number of rings of leather strongly compressed by the two flanches, and then turned in a lathe like a block of wood, till the whole fits tight, when dry, into the barrel. It will swell, says he, and soften with the water, and withstand the greatest pressures. We cannot help thinking this but an indifferent piston. When

it wears, there is nothing to squeeze it to the barrel. It may indeed be taken out and another ring or two of leather put in, or the flanches may be more strongly screwed together: but all this may be done with any kind of piston; and this has therefore no peculiar merit.

13. The following is, we think, greatly preferable. ABCD (fig. 24.), is the solid wooden or metal block of the piston; EF is a metal plate, which is turned hollow or dish-like below, so as to receive within it the solid block. The piston-rod goes through the whole, and has a shoulder above the plate EF, and a nut H below. Four screw-bolts also go through the whole, having their heads sunk into the block, and nuts above. The packing, or stuffing, as it is termed by the workmen, is represented at NO. This is made as solid as possible, and generally consists of soft hempen twine well soaked in a mixture of oil, tallow, and rosin. The plate EF is gently screwed down, and the whole is then put into the barrel, fitting it as tight as may be thought proper. When it wears loose, it may be tightened at any time by screwing down the nuts which cause the edges of the dish to squeeze out the packing, and compresses it against the barrel to any degree.

The greatest difficulty in the construction of a piston is to give a sufficient passage through it for the water, and yet allow a firm support for the valve, and fixture for the piston-rod. It occasions a considerable expense of the moving power to force a piston with a narrow perforation through the water lodged in the working barrel. When we are raising water to a small height, such as 10 or 20 feet, the power so expended amounts to a fourth part of the whole, if the water-way in the piston is less than one-half of the section of the barrel, and the velocity of the piston two feet per second, which is very moderate. There can be no doubt, therefore, that metal pistons are preferable, because their greater strength allows much wider apertures.

14. The following piston, described and recommended by Belidor, seems as perfect in these respects as the nature of things will allow. We shall therefore describe it in the author's own words, as a model which may be adopted with confidence in the greatest works.

"The body of the piston is a truncated metal cone CCXX (fig. 25.), having a small fillet at the greater end. Fig. 26. shows the profile, and fig. 27, the plan of its upper base; where appears a cross bar DD, pierced with an oblong mortise E for receiving the tail of the piston-rod. A band of thick and uniform leather AA (fig. 26. and 28.) is put round this cone, and secured by a brass hoop BB firmly driven on its smaller

end, where it is previously made thinner to give room for the hoop.

"This piston is covered with a leather valve, fortified with metal plates GG (fig. 29.). These plates are wider than the hole of the piston, so as to rest on its rim. There are similar plates below the leather, of a smaller size, that they may go into the hollow of the piston; and the leather is firmly held between the metal plates by screws H, H, which go through all. This is represented by the dotted circle IK. Thus the pressure of the incumbent column of water is supported by the plates GG, whose circular edges rest on the brim of the water-way, and thus straight edges rest on the cross-bar DD of fig. 26 and 27. This valve is laid on the top of the conical box in such a manner that its middle FF rests on the cross-bar. To bind all together, the end of the piston-rod is formed like a cross, and the arms MN (fig. 30.) are made to rest on the diameter FF of the valve, the tail EP going through the hole E in the middle of the leather, and through the mortise E of the cross-bar of the box; as well as through another bar QR (fig. 28, and 29.) which is notched into the lower brim of the box. A key V is then driven into the hole T in the piston-rod; and this wedges all fast. The bar QR is made strong; and its extremities project a little, so as to support the brass hoop BB which binds the leather band to the piston-box."

This piston has every advantage of strength, tightness, and large water-way. The form of the valve (which has given it the name of the *butterfly-valve*) is extremely favourable to the passage of the water; and as it has but half the motion of a complete circular valve, less water goes back while it is shutting.

15. The following piston is also ingenious, and has a good deal of merit. OPPO (pl. XXIV. fig. 5.) is the box of the piston, having a perforation Q, covered above with a flat valve K, which rests in a metal plate that forms the top of the box. ABCBA is a stirrup of iron to which the box is fixed by screws *a, a, a, a,* whose heads are sunk in the wood. This stirrup is perforated at C, to receive the end of the piston-rod, and a nut H is screwed on below to keep it fast. DEFED is another stirrup, whose lower part at DD forms a hoop like the sole of a stirrup, which embraces a small part of the top of the wooden box. The lower end of the piston-rod is screwed; and before it is put into the holes of the two stirrups (through which holes it slides freely), a broad nut G is screwed on it. It is then put into the holes, and the nut H firmly screwed up. The packing RR is then wound about the piston as tight as possible, till it completely fills the working-barrel of the pump. When long use has rendered it in any degree loose, it may be tightened again by screwing down the nut G. This causes the ring DD

to compress the packing between it and the projecting shoulder of the box at PP; and thus causes it to swell out, and apply itself closely to the barrel. Prony, in his Architecture Hydraulique, ascribes this invention to M. Bettancourt.

16. We shall add only another form of a perforated piston; which being on a principle different from all the preceding, will suggest many others; each of which will have its peculiar advantages. OO in fig. 3. pl. XXIV. represents the box of this piston, fitted to the working-barrel in any of the preceding ways as may be thought best. AB is a cross-bar of four arms, which is fixed to the top of the box. CF is the piston-rod going through a hole in the middle of AB, and reaching a little way beyond the bottom of the box. It has a shoulder D, which prevents its going too far through. On the lower end there is a thick metal plate, turned conical on its upper side, so as to fit a conical seat PP in the bottom of the piston-box.

When the piston-rod is pushed down, the friction on the barrel prevents the box from immediately yielding. The rod therefore slips through the hole of the cross-bars AB. The plate E therefore detaches itself from the box. When the shoulder D presses on the bar AB, the box must yield, and be pushed down the barrels, and the water gets up through the perforation. When the piston-rod is drawn up again, the box does not move till the plate E lodges in the seat PP, and thus shuts the water-way; and then the piston lifts the water which is above it, and acts as the piston of a sucking-pump.

This is a very simple and effective construction, and makes a very tight valve. It has been much recommended by engineers of the first reputation, and is frequently used; and, from its simplicity, and the great solidity of which it is capable, it seems very fit for great works. But it is evident that the water-way is limited to less than one-half of the area of the working-barrel. For, if the perforation of the piston be one-half of the area, the diameter of the plate or ball EF must be greater; and therefore less than half the area will be left for the passage of the water by its sides.

17. We come now to consider briefly the forms which may be given to the *valves* of an hydraulic engine.

The requisites of a valve are, that it shall be tight, of sufficient strength to resist the great pressures to which it is exposed, that it afford a sufficient passage for the water, and that it do not allow much to go back while it is shutting.

The butterfly-valve represented in figures 29, &c. is free from most of the inconveniences, and seems the most perfect, of the clack valves. Some engineers make their great valves of a pyramidal form, consisting of four clacks, whose hinges are in the

circumference of the water-way, and which meet with their points in the middle, and are supported by four ribs which rise up from the sides, and unite in the middle. This is an excellent form, affording the most spacious water-way, and shutting very readily. It seems to be the best possible for a piston. The rod of the piston is branched out on four sides, and the branches go through the piston-box, and are fastened below with screws. These branches form the support for the four clacks. We have seen a valve of this form in a pump of six feet diameter, which discharged 20 hogsheads of water every stroke, and made 12 strokes in a minute, raising the water above 22 feet.

18. There is another form of valve, called the *button* or *tail-valve*. It consists of a plate of metal AB (fig. 4. pl. XXIV.) turned conical, so as exactly to fit the conical cavity *ab* of its box. A tail CD projects from the under side, which passes through a cross-bar EF in the bottom of the box, and has a little knob at the end, to hinder the valve from rising too high.

This valve, when nicely made, is unexceptionable. It has great strength, and is therefore proper for all severe strains, and it may be made perfectly tight by grinding. Accordingly it is used in all cases where this is of indispensable consequence. It is most durable, and the only kind that will do for passages where steam or hot water is to go through. Its only imperfection is a small water-way; which, from what has been said, cannot exceed, nor indeed equal, one-half of the area of the pipe.

If we endeavour to enlarge the water-way, by giving the cone very little taper, the valve frequently sticks so fast in the seat that no force can detach them.—And this sometimes happens during the working of the machine; and the jolts and blows given to the machine in taking it to pieces, in order to discover what has been the reason that it has discharged no water, frequently detaches the valve, and we find it quite loose, and cannot tell what has deranged the pump. When this is guarded against, and the diminution of the water-way is not of very great consequence, this is the best form of a valve.

19. Analogous to this is the simplest of all valves. It is nothing more than a sphere of metal, to which is fitted a seat with a small portion of a spherical cavity. Nothing can be more effectual than this valve; it always falls into its proper place, and in every position fits it exactly. Its only imperfection is the great diminution of the water-way. If the diameter of the sphere do not considerably exceed that of the hole, the touching parts have very little taper, and it is very apt to stick fast. It opposes much less resistance to the passage of the water than the flat under-surface of the button-valve. The spherical valve must not be made too light, otherwise it will be hurried up by the water, and much may go back while it is returning to its place.

Belidor describes with great minuteness (vol. ii. p. 221, &c.) a valve which unites every requisite. But it is of such nice and delicate construction, and its defects are so great when this exactness is not attained, or is impaired by use, that we think it hazardous to introduce it into a machine in a situation where an intelligent and accurate artist is not at hand. For this reason we have omitted the description, which cannot be given in few words, nor without many figures; and desire our curious readers to consult that author, or peruse Dr. Desaguliers's translation of this passage. Its principle is precisely the same with the following rude contrivance.

20. Suppose ABCD (fig. 2. plate XXIV.) to be a square wooden trunk. EF is a piece of oak board, exactly fitted to the trunk in an oblique position, and supported by an iron pin which goes through it at I, one-third of its length from its lower extremity E. The two ends of this board are bevelled, so as to apply exactly to the sides of the trunk. It is evident, that if a stream of water come in the direction BA, its pressure on the part IF of this board will be greater than that upon EI. It will therefore force it up and rush through, making it stand almost parallel to the sides of the trunk. To prevent its rising so far, a pin must be put in its way. When this current of water changes its direction, the pressure on the upper side of the board being again greatest on the portion IF, it is forced back again to its former situation; and its two extremities resting on the opposite sides of the trunk, the passage is completely stopped. This board therefore performs the office of a valve; and this valve is the most perfect that can be, because it offers the freest passage to the water, and it allows very little to get back while it is shutting; for the part IE brings up half as much water as IF allows to go down. It may be made extremely tight, by fixing two thin fillets H and G to the sides of the trunk, and covering those parts of the board with leather which apply to them; and in this state it perfectly resembles Belidor's fine valve.

21. This construction of the valve suggests, by the way, a form of an occasional pump, which may be quickly set up by any common carpenter, and will be very effectual in small heights. Let *abcde* (fig. 2.) be a square box made to slide along this wooden trunk without shake, having two of its sides projecting upwards, terminating like the gable ends of a house. A piece of wood *e* is mortised into these two sides, and to this the piston-rod is fixed. This box being furnished with a valve similar to the one below, will perform the office of a piston. If this pump be immersed so deep in the water that the piston shall also be under water, we scruple not to say that its perform-

ance will be equal to any. The piston may be made abundantly tight, by covering its outside neatly with soft leather. And as no pipe can be bored with greater accuracy than a very ordinary workman can make a square trunk, we think this pump will not be very deficient even for a considerable suction.

Thus much will, we hope, suffice for the descriptive part of these useful machines: as to the theory of the *motion* of water in pumps, at the same time that it is extremely intricate, it presents but few results that are of any practical utility. The curious student may be referred to the *Maschinenlehre* of Langsdorf, the *Hydrodynamique* of Bossut, the *Hydraulique* of Buat, Hachette's *Traité Elémentaire des Machines*, the *Architecture Hydraulique* of Prony, and the article *Pump* in the Encyclopædia Britannica. The last two pieces have furnished us with the most valuable parts of the present article. Some remarks on the variable motion of the piston-rod may be seen under the title PARALLEL *motion* in this volume.

PYROMETER, a machine contrived to measure the expansion of metals, and other bodies, occasioned by heat.

Muschenbroeck was the original inventor of the Pyrometer: the nature and construction of his instrument may be understood from the following account. If we suppose a small bar of metal, 12 or 15 inches in length, made fast at one of its extremities, it is obvious that if it be dilated by heat it will become lengthened, and its other extremity will be pushed forwards. If this extremity then be fixed to the end of a lever, the other end of which is furnished with a pinion, adapted to a wheel, and if this wheel move a second pinion, the latter a third, and so on, it will be evident that by multiplying wheels and pinions in this manner, the last will have a very sensible motion; so that the moveable extremity of the small bar cannot pass over the hundredth or thousandth part of a line, without a point of the circumference of the last wheel passing over several inches. If this circumference then have teeth fitted into a pinion, to which an index is attached, this index will make several revolutions, when the dilatation of the bar amounts only to a quantity altogether insensible. The portions of this revolution may be measured on a dial-plate, divided into equal parts; and by means of the ratio which the wheels bear to the pinions, the absolute quantity which a certain degree of heat may have expanded the small bar can be ascertained: or, conversely, by the dilatation of the small bar the degree of heat which has been applied to it may be determined.

Such is the construction of Muschenbroeck's pyrometer. It is necessary to observe that a small cup is adapted to the ma-

chine, in order to receive the liquid or fused matters, subjected to experiment, and in which the bar to be tried is immersed.

When it is required to measure, by this instrument, a considerable degree of heat, such as that of boiling oil or fused metal, fill the cup with the matter to be tried, and immerse the bar of iron into it. The dilatation of the bar, indicated by the index, will point out the degree of heat it has assumed, and which must necessarily be equal to that of the matter into which it is immersed.

This machine evidently serves to determine the ratio of the dilatation of metals, &c.: for by substituting in the room of the pyrometric bar other metallic bars of the same length, and then exposing them to an equal degree of heat, the ratios of their dilatation will be shown by the motion of the index.

Muschenbroeck has given a table of the expansion of the different metals, in the same degree of heat. Having prepared cylindric rods of iron, steel, copper, brass, tin, and lead, he exposed them first to a *pyrometer* with one flame in the middle; then with two flames; and successively to one with three, four, and five flames. But previous to this trial, he took care to cool them equally, by exposing them some time upon the same stone, when it began to freeze, and Fahrenheit's thermometer was at thirty-two degrees. The effects of these experiments are digested in the following table, where the degrees of expansion are marked in parts equal to the $\frac{1}{12500}$ part of an inch.

Expansion of	Iron	Steel	Copper	Brass	Tin	Lead
By one flame	80	85	89	110	153	155
By two flames placed close together	117	123	115	220		274
By two flames $2\frac{1}{2}$ inches distant	109	94	92	141	219	263
By three flames placed close together	142	168	193	275		
By four flames placed close together	211	270	270	361		
By five flames	230	310	310	377		

It is to be observed of tin, that it will easily melt, when heated

by two flames placed together. Lead commonly melts with three flames, placed together, especially if they burn long.

From these experiments, so far as they are correct, it appears, at first view, that iron is the least expanded of any of these metals, whether it be heated by one or more flames; and therefore is most proper for making machines or instruments which we would have free from any alterations by heat or cold, as the rods of pendulums, for clocks, &c. So likewise the measures of yards or feet should, if of metal, be made of iron, that their length may be as nearly as possible the same, summer and winter. The expansion of lead and tin, by only one flame, is nearly the same; that is, almost double of the expansion of iron. It is likewise observable, that the flames placed together cause a greater rarefaction than when they have a sensible interval between them; iron, in the former case, being expanded 117 degrees, and only 109 in the latter; the reason of which difference is obvious. By comparing the expansions of the same metal, produced by one, two, three, or more flames, it appears, that two flames do not cause double the expansion of one; nor three flames three times that expansion, but always less; and these expansions differ so much the more from the ratio of the number of flames, as there are more flames acting at the same time. It is also observable, that metals are not expanded equally at the time of their melting, but some more, some less. Thus tin began to run, when rarefied 219 degrees; whereas brass was expanded 377 degrees, and yet was far from melting.

By the help of this instrument Mr. Ellicott found upon a medium, that the expansions of bars of different metals, as nearly of the same dimensions as possible, by the same degree of heat, were as follow:

Gold,	Silver,	Brass,	Copper,	Iron,	Steel,	Lead,
73	103	95	89	60	56	149

The great difference between the expansions of iron and brass has been applied with good success to remedy the irregularities in pendulums arising from heat. (Phil. Trans. vol. xlvii. p. 485.) See PENDULUM.

Mr. Graham used to measure the minute alterations, in length, of metal bars, by advancing the point of a micrometer-screw, till it sensibly stopped against the end of the bar to be measured. This screw, being small and very lightly hung, was capable of agreement within the three or four-thousandth part of an inch. On this general principle Mr. Smeaton contrived his pyrometer, in which the measures are determined by the contact of a piece of metal with the point of a micrometer-screw.

The following table shows how much a foot in length of each metal grows longer by an increase of heat, corresponding to 180° of Fahrenheit's thermometer, or to the difference between freezing and boiling water, expressed in parts of which the unit is equal to the 10,000 part of an inch.

1.	White glass barometer tube,	100
2.	Martial regulus of antimony,	130
3.	Blistered steel,	138
4.	Hard steel,	147
5.	Iron,	151
6.	Bismuth,	167
7.	Copper, hammered,	204
8.	Copper eight parts, with tin one,	218
9.	Cast brass,	225
10.	Brass sixteen parts, with tin one,	229
11.	Brass wire,	232
12.	Speculum metal,	232
13.	Spelter solder, viz. brass two parts, zinc one,	247
14.	Fine pewter,	274
15.	Grain tin,	298
16.	Soft solder, viz. lead two, tin one,	301
17.	Zinc eight parts, with tin one, a little hammered,	323
18.	Lead,	344
19.	Zinc or spelter,	353
20.	Zinc hammered half an inch per foot,	373

See, for a more copious table, Mr. Bailey's paper on the mercurial pendulum in vol. 1. Transactions of the Astronomical Society of London.

M. de Luc, in consequence of a hint suggested to him by the late Mr. Ramsden, invented a pyrometer, the basis of which is a rectangular piece of deal board two feet and a half long, 15 inches broad, and one inch and a half thick; and to this all the other parts are fixed. This is mounted in the manner of a table, with four deal legs, each a foot long and an inch and a half square, well fitted near its four angles, and kept together at the other ends by four firm cross pieces. This small table is suspended by a hook to a stand; the board being in a vertical situation in the direction of its grain, and bearing its legs forward in such a manner as that the cross-pieces which join them may form a frame, placed vertically facing the observer. This frame sustains a microscope, which is firmly fixed in another frame, that moves in the former by means of grooves, but with a very considerable degree of tightness; the friction of which may be increased by

the pressure of four screws. The inner sliding frame, which is likewise of deal, keeps the tube of the microscope in a horizontal position, and in great part without the frame, insomuch that the end which carries the lens is but little within the space between the frame and the board. This microscope is constructed in such a manner as that the object observed may be an inch distant from the lens; and it has a wire which is situated in the focus of the glasses, in which the objects appeared reversed. At the top of the apparatus there is a piece of deal, an inch and a half thick and two inches broad, laid in a horizontal direction from the board to the top of the frame. To this piece the rods of the different substances, whose expansion by heat is to be measured, are suspended: one end of it slides into a socket, which is cut in the thickness of the board; and the other end, which rests upon the frame, meets there with a screw which makes the piece move backward and forward, to bring the objects to the focus of the microscope. There is a cork very strongly driven through a hole bored vertically through this piece; and in another vertical hole made through the cork, the rods are fixed at the top; so that they hang only, and their dilatation is not counteracted by any pressure. In order to heat the rods, a cylindrical bottle of thin glass, about 21 inches high, and four inches in diameter, is placed in the inside of the machine, upon a stand independent of the rest of the apparatus. In this bottle the rods are suspended at a little less than an inch distance from one of the insides, in order to have them near the microscope. Into it is poured water of different degrees of heat, which must be stirred about, by moving upwards and downwards, at one of the sides of the bottle, a little piece of wood, fastened horizontally at the end of a stick: in this water is hung a thermometer, the ball of which reaches to the middle of the height of the rods. During these operations the water rises to the cork, which thus determines the length of the heated part; the bottle is covered, to prevent the water from cooling too rapidly at the surface; and a thin case of brass prevents the vapour from fixing upon the piece of deal to which the rods are fixed.

The late Mr. Ferguson also invented two pyrometers, descriptions and figures of which are given in his Lectures.

Mr. Wedgwood, the ingenious manufacturer of the finest earthenware from basaltic masses, or *terra cotta*, has contrived a curious pyrometer: he employs small cubes of dry clay; because that species of earth has the remarkable property of *contracting* in its bulk, when submitted to the fire, and not again expanding on suddenly exposing it to the cold air. In order to ascertain the precise degree of heat in an oven, he puts one of his clay

cubes into it; and, after having acquired the temperature of the place, he immediately plunges it into cold water. Now, the size of the cube (that was exactly adjusted to half an inch square) is measured between two brass rules, the sides of which are somewhat obliquely disposed, so as to form an inclining groove, into which the cube may be slidden. In proportion as the bulk of the latter has been contracted by heat, it passes down deeper between the scales, on which the various degrees of temperature have been previously marked. Thus, when the division of the scale commences from the point of red heat visible in day-light, and the whole range is divided into 240 equal parts, it will be found that Swedish copper melts at 28; gold at 32; iron at from 130 to 150 degrees: above this point, the cubes could not be heated. But if one of these clay squares be put into an oven where other materials, such as bread, earthenware, &c. are to be baked, they may be usefully employed, for regulating the necessary degree of heat.

M. Fourmy has lately given, in the *Journal des Mines*, a paper "On the Thermometers of baked Earths, termed Pyrometers;" in which he shows that the effect of shrinking, upon which Wedgwood's pyrometer is founded, does not result solely and invariably from the cause to which it is ascribed; that it is not necessarily proportionate to it; that whatever may be the graduation and the continuity of temperature applied to an aluminous mixt, its shrinking is not only not necessarily graduated, or necessarily continuous, but it also does not always necessarily take place; and therefore that a pyrometer founded upon such shrinking does not afford so constant and accurate a measure for the highest degrees of heat, as the dilatation of mercury or of alcohol does for the lower. A translation of M. Fourmy's observations is inserted in the *Repertory of Arts*, &c No. 38. N. S.

Mr. Gurney has lately invented and exhibited in his lectures, a pyrometer for ascertaining the relative expansibility of the various metals which can be drawn into wire, of which the following account has been published in the *Register of Arts and Sciences*.

The wire, *a*, (fig. 4. pl. XLIV.) being attached at the lower end to a peg, is passed successively round four or five little pulley wheels, fixed by their axles upon a piece of board, and arranged in the manner shown. From the uppermost pulley the wire proceeds out of the vessel and passes over a small central wheel *b* of the dial plate, and from thence descending, a weight *c* is appended to that end, which preserves the wire in a state of tension. Thus prepared, the apparatus is immersed in a vessel of water or other fluid heated to any desired tem-

perature, which is ascertained by a thermometer being suspended therein. The expansion that then takes place by the increase of heat is accurately denoted by the index *b* on the graduated scale of the dial, the index being fixed to the central wheel moves round as the wire elongates. Upon abstracting the heat, the wire contracts, and draws back the wheel and index to its original position.

By this excellent contrivance it is evident that a table of the expansibility of the metals, at given temperatures, may be formed with the utmost precision, which would become information of a most desirable nature in many branches of the arts but particularly in the construction of time-pieces.

The sketch for the engraving was made from memory, so that the central wheel of the dial on which the index is fixed is drawn rather too large in proportion; for indeed it must be obvious that the smaller the dimensions of this wheel, and the larger those of the dial, the more sensible and delicate will be the indications of expansion. If the little wheel were to be one inch in circumference, and the circle of the scale 100 inches, then the elongation of wire to the extent of a tenth of an inch would cause the index to move over a space of ten inches. We understand that Mr. Gurney constructed one on these principles, that showed even the variations in the temperature of the atmosphere with very great exactness.

RAMSDEN's MACHINE *for dividing* MATHEMATICAL INSTRUMENTS is a useful invention, by which these divisions can be performed with exceedingly great accuracy, such as would formerly have been deemed incredible. On discovering the method of constructing this machine, its inventor, Mr. Jesse Ramsden, received 615*l.* from the commissioners of longitude; engaging himself to instruct a certain number of persons, not exceeding ten, in the method of making and using this machine from the 28th October 1775, to 28th October 1777: also binding himself to divide all octants and sextants by the same engine, at the rate of three shillings for each octant, and six shillings for each brass sextant, with Nonius's divisions to half-minutes, for as long time as the commissioners should think proper to let the engine remain in his possession. Of this sum of 615*l.* paid to Mr. Ramsden, 300*l.* were given him as a reward for the improvement made by him in discovering the engine, and the remaining 315*l.* for his giving up the property of it to the commissioners. The following description of the engine is that given upon oath by Mr. Ramsden himself.

" This engine consists of a large wheel of bell-metal, supported on a mahogany stand, having three legs, which are strongly connected together by braces, so as to make it per-

fectly steady. On each leg of the stand is placed a conical friction-pulley, whereon the dividing wheel rests: to prevent the wheel from sliding off the friction-pulleys, the bell-metal centre under it turns in a socket on the top of the stand.

"The circumference of the wheel is ratched or cut (by a method which will be described hereafter) into 2160 teeth, in which an endless screw acts. Six revolutions of the screw will move the wheel a space equal to one degree.

"Now a circle of brass being fixed on the screw arbor, having its circumference divided into 60 parts, each division will consequently answer to a motion of the wheel of 10 seconds, six of them will be equal to a minute, &c.

"Several different arbors of tempered steel are truly ground into the socket in the centre of the wheel. The upper parts of the arbors that stand upon the plane are turned of various sizes, to suit the centres of different pieces of work to be divided.

"When any instrument is to be divided, the centre of it is very exactly fitted on one of these arbors; and the instrument is fixed down to the plane of the dividing wheel, by means of screws, which fit into holes made in the radii of the wheel for that purpose.

"The instrument being thus fitted on the plane of the wheel, the frame which carries the dividing point is connected at one end by finger screws with the frame which carries the endless screw; while the other end embraces that part of the steel arbor which stands above the instrument to be divided, by an angular notch in a piece of hardened steel: by this means both ends of the frame are kept perfectly steady, and free from any shake.

"The frame carrying the dividing-point or tracer is made to slide on the frame which carries the endless screw to any distance from the centre of the wheel as the radius of the instrument to be divided may require, and may be there fastened by tightening two clumps; and the dividing-point or tracer being connected with the clumps by the double jointed frame, admits a free and easy motion towards or from the centre for cutting the divisions, without any lateral shake.

"From what has been said, it appears that an instrument thus fitted on the dividing-wheel may be moved to any angle by the screw and divided circle on its arbor, and that this angle may be marked on the limb of the instrument with the greatest exactness by the dividing-point or tracer, which can only move in a direct line tending to the centre, and is altogether freed from those inconveniences that attend cutting by means of a straight edge. This method of drawing lines will also prevent

any error that might arise from an expansion or contraction of the metal during the time of dividing.

"The screw frame is fixed on the top of a conical pillar, which turns freely round its axis, and also moves freely towards or from the centre of the wheel, so that the screw-frame may be entirely guided by the frame which connects it with the centre: by this means any eccentricity of the wheel and the arbor would not produce any error in the dividing; and by a particular contrivance (which will be described hereafter), the screw when pressed against the teeth of the wheel always moves parallel to itself; so that a line joining the centre of the arbor and the tracer continued will always make equal angles with the screw.

"Fig. 1. in pl. XXVI. represents a perspective view of the engine.

"Fig. 2. in pl. XXVII. is a plan, of which fig. 3. represents a section on the line Π Δ.

"The large wheel A is 45 inches in diameter, and has ten radii, each being supported by edge-bars, as represented in fig. 3. These bars and radii are connected by the circular ring B, 24 inches in diameter and 3 deep; and, for greater strength, the whole is cast in one piece in bell-metal.

"As the whole weight of the wheel A rests on its ring B, the edge bars are deepest where they join it; and from thence their depth diminishes, both towards the centre and circumference, as represented in fig. 3.

"The surface of the wheel A was worked very even and flat, and its circumference turned true. The ring C, of fine brass, was fitted very exactly on the circumference of the wheel; and was fastened thereon with screws, which after being screwed as tight as possible, were well riveted. The face of a large chuck being turned very true and flat in the lathe, the flattened surface A (fig. 3.) of the wheel was fastened against it with holdfasts; and the two surfaces and circumference of the ring C, a hole through the centre and the plane part round [b] it, and the lower edge of the ring B, were turned at the same time.

"D is a piece of hard bell-metal, having the hole, which receives the steel arbor [d], made very straight and true. This bell-metal was turned very true on an arbor; and the face, which rests on a wheel at [b], was turned very flat, so that the steel arbor [d] might stand perpendicular to the plane of the wheel: this bell-metal was fastened to the wheel by six steel screws [l].

"A brass socket Z is fastened on the centre of the mahogany stand, and receives the lower part of the bell-metal piece D,

being made to touch the bell-metal in a narrow part near the mouth, to prevent any obliquity of the wheel from bending the arbor: good fitting is by no means necessary here; since any shake in this socket will produce no bad effect, as will appear hereafter when we describe the cutting-frame.

"The wheel was then put on its stand, the lower edge of the ring B (fig. 1, 2, and 3.) resting on the circumference of three conical friction-pulleys W, to facilitate its motion round its centre. The axis of one of these pulleys is in a line joining the centre of the wheel, and the middle of the endless screw, and the other two placed so as to be at equal distances from each other.

"(Fig. 1.) is a block of wood strongly fastened to one of the legs of the stand; the piece [g] is screwed to the upper side of the block, and has half-holes, in which the transverse axis [h] (fig. 4.) turns: the half holes are kept together by the screws [i].

The lower extremity of the conical pillar P (fig. 1 and 4.) terminates in a cylindrical steel pin [k], (fig. 4.) which passes through and turns in the transverse axis [h], and is confined by a cheek and screw.

"To the upper end of the conical pillar is fastened the frame G, (fig. 4.) in which the endless screw turns: the pivots of the screw are formed in the manner of two frustums of cones joined by a cylinder, as represented at X (fig. 5.). These pivots are confined between half-poles, which press only on the conical parts, and do not touch the cylindric parts: the half-holes are kept together by screws [a] which may be tightened at any time, to prevent the screw from shaking in the frame.

"On the screw-arbor is a small wheel of brass K (fig. 1, 2, 4, 5.), having its outside edge divided into 60 parts, and numbered at every 6th division with 1, 2. &c. to 10. The motion of this wheel is shown by the index [y] (fig. 4 and 5.) on the screw-frame G.

"H (fig. 1.) represents a part of the stand, having a parallel slit in the direction towards the centre of the wheel, large enough to receive the upper part of the conical brass pillar P, which carries the screw and its frame: and as the resistance, when the wheel is moved by the endless-screw, is against the side of the slit H which is towards the left hand, that side of the slit is faced with brass, and the pillar is pressed against it by a steel spring on the opposite side: by this means the pillar is strongly supported laterally, and yet the screw may be easily pressed from or against the circumference of the wheel, and the pillar will turn freely on its axis to take any direction given it by the frame L.

"At each corner of the piece I (fig. 4.) are screws [n] of tempered steel, having polished conical points: two of them turn in conical holes in the screw-frame near [o], and the points of the other two screws turn in the holes in the piece Q; the screws [p] are of steel, which being tightened, prevent the conical pointed screws from unturning when the frame is moved.

"L (fig. 1, 2, 6.) is a brass frame, which serves to connect the endless screw, its frame, &c. with the centre of the wheel: each arm of this frame is terminated by a steel screw, that may be passed through any of the holes [q] in the piece Q (fig. 4.), as the thickness of work to be divided on the wheel may require, and are fastened by the finger-nuts [r] (fig. 1 and 2.)

"At the other end of this frame is a flat piece of tempered steel [b] (fig. 6.), wherein is an angular notch: when the endless-screw is pressed against the teeth of the circumference of the wheel, which may be done by turning the finger-screw S (fig. 1. and 2.) to press against the spring [t], this notch embraces and presses against the steel arbor [d]. This end of the frame may be raised or depressed by moving the prismatic slide [u] (fig. 2.) which may be fixed at any height by the four steel screws [v] (fig. 1, 2, 6.)

"The bottom of this slide has a notch [k] (fig. 1. and 6.), whose plane is parallel to the endless-screw; and by the point of the arbor [d] (fig. 3.) resting in this notch, this end of the frame is prevented from tilting. The screw S (fig. 1, 2.) is prevented from unturning, by tightening the finger-nut [w].

"The teeth on the circumference of the wheel were cut by the following method:

"Having considered what number of teeth on the circumference would be most convenient, which in this engine is 2160, or 360 multiplied by 6, I made two screws of the same dimensions, of tempered steel, in the manner hereafter described, the interval between the threads being such as I knew by calculation would come within the limits of what might be turned off the circumference of the wheel: one of these screws, which was intended for ratching or cutting the teeth, was notched across the threads, so that the screw, when pressed against the edge of the wheel and turned round, cut in the manner of a saw. Then having a segment of a circle a little greater than 60 degrees, of about the same radius with the wheel, and the circumference made true, from a very fine centre, I described an arch near the edge, and set off the chord of 60 degrees on this arch. This segment was put in the place of the wheel, the edge of it was ratched, and the number of revolutions and parts of the screw contained between the interval of the 60 degrees were counted.

The radius was corrected in the proportion of 360 revolutions, which ought to have been in 60 degrees, to the number actually found; and the radius, so corrected, was taken in a pair of beam-compasses: while the wheel was on the lathe, one foot of the compasses was put in the centre, and with the other a circle was described on the ring; then half the depth of the threads of the screw being taken in dividers, was set from this circle outwards, and another circle was described cutting this point; a hollow was then turned on the edge of the wheel of the same curvature as that of the screw at the bottom of the threads: the bottom of this hollow was turned to the same radius or distance from the centre of the wheel, as the outward of the two circles before mentioned.

"The wheel was now taken off the lathe; and the bell-metal piece D (fig. 3.) was screwed on as before directed, which after this ought not to be removed.

"From a very exact centre a circle was described on the ring C (fig. 1, 2, 3.) about $\frac{4}{10}$ of an inch within where the bottom of the teeth would come. This circle was divided with the greatest exactness I was capable of, first into five parts, and each of these into three. These parts were then bisected four times; (that is to say), supposing the whole circumference of the wheel to contain 2160 teeth, this being divided into five parts, each would contain 432 teeth; which being divided into three parts, each of them would contain 144; and this space bisected four times would give 72, 36, 18, and 9: therefore each of the last divisions would contain nine teeth. But as I was apprehensive some error might arise from quinquesection and trisection, in order to examine the accuracy of the divisions, I described another circle on the ring C (fig. 7.) $\frac{1}{10}$ inch within the former, and divided it by continual bisections, as 2160, 1080, 540, 270, 135, $67\frac{1}{2}$, and $33\frac{3}{4}$; and as the fixed wire (to be described presently) crossed both the circles, I could examine their agreement at every 135 revolutions; (after ratching, could examine it at every $33\frac{3}{4}$): but, not finding any sensible difference between the two sets of divisions, I, for ratching, made choice of the former; and, as the coincidence of the fixed wire with an intersection could be more exactly determined than with a dot or division, I therefore made use of intersections in both circles before described.

"The arms of the frame L (fig. 7.) were connected by a thin piece of brass of $\frac{3}{4}$ of an inch broad, having a hole in the middle of $\frac{4}{10}$ of an inch in diameter; across this hole a silver wire was fixed exactly in a line to the centre of the wheel: the coincidence of this wire with the intersections was examined by a lens $\frac{7}{10}$ inch focus, fixed in a tube which was attached to

one of the arms L*. Now a handle or winch being fixed on the end of the screw, the division marked 10 on the circle K was set to its index, and, by means of a clamp and adjusting-screw for that purpose, the intersection marked 1 on the circle C was set exactly to coincide with the fixed wire; the screw was then carefully pressed against the circumference of the wheel, by turning the finger-screw S; then, removing the clamp, I turned the screw by its handle 9 revolutions, till the intersection marked 240 came nearly to the wire; then, unturning the finger-screw S, I released the screw from the wheel, and turned the wheel back till the intersection marked 2 exactly coincided with the wire; and, by means of the clamp before mentioned, the division 10 on the circle being set to its index, the screw was pressed against the edge of the wheel by the finger-screw S; the clamps were removed, and the screw turned nine revolutions till the intersection marked 1 nearly coincided with the fixed wire; the screw was released from the wheel by unturning the finger-screw S as before; the wheel was turned back till the intersection 3 coincided with the fixed wire; the division 10 on the circle being set to its index, the screw was pressed against the wheel as before, and the screw was turned 9 revolutions, till the intersection 2 nearly coincided with the fixed wire, and the screw was released; and I proceeded in this manner till the teeth were marked round the whole circumference of the wheel. This was repeated three times round, to make the impression of the screw deeper. I then ratched the wheel round continually in the same direction without ever disengaging the screw; and in ratching the wheel about 300 times round, the teeth were finished.

"Now it is evident, if the circumference of the wheel was even one tooth or ten minutes greater than the screw would require, this error would in the first instance be reduced to $\frac{1}{240}$ part of a revolution, or two seconds and a half; and these errors or inequalities of the teeth were equally distributed round the wheel at the distance of nine teeth from each other. Now, as the screw in ratching had continually hold of several teeth at the same time, and these constantly changing, the above-mentioned inequalities soon corrected themselves, and the teeth were reduced to a perfect equality. The piece of brass which carries the wire was now taken away, and the cutting-screw was also removed, and a plain one (hereafter described) put in its place: on one end of the screw is a small brass circle, having its edge divided into 60 equal parts, and numbered at every sixth

* The intersections are marked for the sake of illustration, though properly invisible, they lying under the brass plate.

division, as before mentioned. On the other end of the screw is a ratchet-wheel C, having 60 teeth, covered by the hollowed circle [d] (fig. 5.), which carries two clicks that catch upon the opposite sides of the ratchet when the screw is to be moved forwards. The cylinder S turns on a strong steel arbor F, which passes through and is firmly screwed to the piece Y: this piece, for greater firmness, is attached to the screw-frame G (fig. 4.) by the braces [v]: a spiral groove or thread is cut on the outside of the cylinder S, which serves both for holding the string, and also giving motion to the lever J on its centre by means of a steel tooth [n], that works between the threads of the spiral. To the lever is attached a strong steel pin [m], on which a brass socket [r] turns: this socket passes through a slit in the piece [p], and may be tightened in any part of the slit by the finger-nut [f]: this piece serves to regulate the number of revolutions of the screw for each tread of the treadle R.

"T (fig. 1.) is a brass box containing a spiral spring; a strong gut is fastened and turned three or four times round the circumference of this box; the gut then passes several times round the cylinder S, and from thence down to the treadle R (fig. 1.). Now, when the treadle is pressed down, the string pulls the cylinder S round its axis, and the clicks catching hold of the teeth on the ratchet carry the screw round with it, till, by the tooth [n] working in the spiral groove, the lever J (fig. 4.) is brought near the wheel [d,] and the cylinder stopped by the screw-head [x] striking on the top of the lever J; at the same time the spring is wound up by the other end of the gut passing round the box T (fig. 1.). Now, when the foot is taken off the treadle, the spring unbending itself pulls back the cylinder, the clicks leaving the ratchet and screw at rest till the piece [t] strikes on the end of the piece [p] (fig. 1.): the number of revolutions of the screw at each tread is limited by the number of revolutions the cylinder is allowed to turn back before the stop strikes on the piece [p].

"When the endless-screw was moved round its axis with a considerable velocity, it would continue that motion a little after the cylinder S (fig. 1 and 4.) was stopped; to prevent this, the angular lever η was made; that when the lever J comes near to stop the screw [x], it, by a small chamfer, presses down the piece $\varkappa$ of the angular lever; this brings the other end η of the same lever forwards, and stops the endless-screw by the steel pin μ striking upon the top of it: the foot of the lever is raised again by a small spring pressing on the brace [v].

"D, two clamps, connected by the piece α, slide one on each arm of the frame L (fig. 1, 2, 6.), and may be fixed at pleasure by the four finger-screws ε, which press against steel springs to

avoid spoiling the arms: the piece [q] is made to turn without shake between two conical pointed screws [f], which are prevented from unturning by tightening the finger-nuts N.

"The piece M (fig. 6.) is made to turn on the piece [q], by the conical pointed screws [s] resting in the hollow centres [e].

"As there is frequent occasion to cut divisions on inclined planes, for that purpose the piece γ, in which the tracer is fixed, has a conical axis at each end, which turn in half holes: when the tracer is set to any inclination, it may be fixed there by tightening the steel screws β.

"*Description of the Engine by which the Endless-screw of the Dividing-engine was cut.*

"Fig. 9. represents this engine of its full dimensions seen from one side.

"Fig. 8. the upper side of the same as seen from above.

"A represents a triangular bar of steel, to which the triangular holes in the pieces B and C are accurately fitted, and may be fixed on any part of the bar by the screws D.

"E is a piece of steel whereon the screw is intended to be cut; which, after being hardened and tempered, has its pivots turned in the form of two frustums of cones, as represented in the drawings of the dividing-engine (fig. 5.). These pivots were exactly fitted to the half-holes F and T, which were kept together by the screws Z.

"H represents a screw of untempered steel, having a pivot I, which turns in the hole K. At the other end of the screw is a hollow centre, which receives the hardened conical point of the steel pin M. When this point is sufficiently pressed against the screw, to prevent its shaking, the steel pin may be fixed by tightening the screws Y.

"N is a cylindric nut, moveable on the screw H; which, to prevent any shake, may be tightened by the screws O. This nut is connected with the saddle-piece P by means of the intermediate universal joint W, through which the arbor of the screw H passes. A front view of this piece, with a section across the screw-arbor, is represented at X. This joint is connected with the nut by means of two steel slips S, which turn on pins between the cheeks T on the nut N. The other ends of these slips S turn in like manner on pins (a). One axis of this joint turns in a hole in the cock (b), which is fixed to the saddle-piece; and the other turns in a hole (d), made for that purpose in the same piece on which the cock (b) is fixed. By this

means, when the screw is turned round, the saddle-piece will slide uniformly along the triangular bar A.

"K is a small triangular bar of well-tempered steel, which slides in a groove of the same form on the saddle-piece P. The point of this bar or cutter is formed to the shape of the thread intended to be cut on the endless-screw. When the cutter is set to take proper hold of the intended screw, it may be fixed by tightening the screws (e), which press the two pieces of brass G upon it.

"Having measured the circumference of the dividing-wheel, I found it would require a screw about one thread in a hundred coarser than the guide screw H. The wheels on the guide-screw arbor H, and that on the steel E, on which the screw was to be cut, were proportioned to each other to produce that effect, by giving the wheel L 198 teeth, and the wheel Q 200. These wheels communicated with each other by means of the intermediate wheel R, which also served to give the threads on the two screws the same direction.

"The saddle-piece P is confined on the bar A by means of the pieces (g), and may be made to slide with a proper degree of tightness by the screws (n)."

For other excellent observations and directions relative to the dividing of instruments, see Mr. Smeaton's paper containing an account of Mr. Hindley's method, *Phil. Trans.* vol. lxxvi. or New Abridgment, vol. xvi. p. 30—56, and the papers of Mr. Troughton, Mr. H. Cavendish, and Professor Lax, in *Phil. Trans.* for 1809, abridged in the Retrospect of Phil. and Mech. Discoveries, No. 23.

REVERSING OF MOTIONS, *contrivances for*. We do not here mean to speak of alternating or reciprocating motions after intervals of short continuance, those being already treated of in the introductory part of this volume, also under the title PARALLEL *motions*, besides that they occur incidentally in the separate descriptions of several machines. We shall now mention some methods of reversing motions after much longer intervals; as in the case of drawing up buckets from wells or mines, where no change of direction may be required for several minutes; or in different kinds of mill-work, where the direction may not be changed for some hours.

Contrivances to effect such reversion of motion are very numerous; but almost all of them may be reduced to two general methods: for the required change is generally produced either by making two equal pinions on one and the same axis take alternately into the teeth of those parts of a larger wheel which are nearly diametrically opposite; or, by means of an

additional wheel which may, as the practical mechanics term it, be thrown in and out of gear alternately.

In many engines for drawing buckets out of mines that are moved by horses, the motion is frequently reversed by turning round the animal, and causing him to retrace his steps and draw the contrary way: but this is found very injurious to the horse, a circumstance which has frequently led to the adoption of other methods. In Emerson's Mechanics a simple contrivance is described, consisting merely of a horizontal face-wheel upon the same vertical shaft as the horsepole is attached to, and two equal pinions upon the same axle as carries the drum or barrel on which the rope winds. The axle which carries the drum and pinions is fixed horizontally, a little above a diameter of the face-wheel; and first one and then the other of the pinions is made to be driven by that wheel; thus manifestly reversing the motion as required. There are two methods of attaching these pinions to the axle, and making them to be acted upon by the face-wheel: in one of them, the pinions are fastened upon the axle at a distance from each other exceeding the diameter of the face-wheel only 3 or 4 inches; then, the axle being moved horizontally through this small distance brings first one and then the other pinion into contact with the wheel at opposite extremities of a diameter, and thus changes the direction of the motion; but this method is attended with the disadvantage of having often to move a heavy weight with the horizontal axle, besides that there is much danger of breaking the teeth of the pinions and wheel when they first come to embrace each other. In the second method, the lanterns or pinions both turn constantly with the face-wheel, but they play freely upon their common axle, except they are stopped by a pin which *fixes* them; the application of such pin to first the one and then the other of the lanterns produces the alternating motion as proposed.

M. Prony has two contrivances for reversing the motion in horse-whims, without changing that of the animal: in both of which, however, the general principle is the same as that adopted by Mr. Emerson. In the first a horizontal wheel, toothed at its face, lay just *above* two vertical pinions, fixed on the opposite extremities of an axis of the length of its diameter. This wheel was so contrived as to incline a little from its horizontal position to either side at pleasure; so that on the one inclination its teeth locked with those of one pinion, and receded from the other; and on the other position, its operation on the pinions was reversed: by which the axis of the pinions turned round first in one direction, and afterwards in the contrary.

M. Prony, finding this method subject to some inconveniences, contrived the following, which he esteems much superior to it. An horizontal wheel, toothed at its face, and attached to a perpendicular arbor (which gives it motion), turns two pinions, moveable on the same axis, which it meets at the opposite sides of its circumference: these pinions are not attached to the axis, but turn round freely upon it: the intermediate part of the axis is square, and has adjoining to each pinion boxes which slide back and forwards on it, each of which supports a faced wheel, with strong serrated teeth; the serration being in a different direction on the opposite wheels: the boxes are connected by two iron bars, so as to change their places by one movement; to the pinions there are also serrated faced wheels attached, so as to lock on those opposite to them on the sliding boxes. From this construction it follows, that when the boxes are slidden to one extremity of the axis, the pinion at that side will be connected with the axle, and communicate its motion to it in one direction; and when the boxes are moved to the other extremity, then the first pinion will be disengaged, and the second be locked to the axle, and cause it to turn round in a direction the reverse of that in which it moved before. There is a lever on another axle, whose office is to move the before-mentioned boxes backwards and forwards: an arm projects from the axis, which moves between two pieces, proceeding from the frame connected with the boxes: the lever rises upwards, and has a weight at its top, by which it presses strongly in either direction, when it passes the perpendicular position; forming thus the contrivance vulgarly called a tumbling-bob, which is used in various engines for a simular purpose. Upon the same axle on which the pinions move is fastened a drum-wheel, round which passes the chain or cord to which the buckets are attached; another chain or cord is placed below the buckets, from the bottom of one to that of the other, to form an equilibrium between the whole of the appendage of one bucket and that of the other in all positions. A bar is so placed, that, on one of the buckets rising to a certain height, it catches the bar, forces it upwards, and thereby throws over the tumbling-bob connected with its other extremity: this reverses the movement of the buckets; and, on the other bucket rising, it operates in the same way on another lever, which throws the bob to the other side, and causes the first bucket to rise again.

M. Prony has annexed a contrivance to this engine by which the horse that puts it in motion is disengaged when any accident happens, which would tend to stop the movement of the wheels: for this purpose the traces pass under two pulleys in

the ends of the yoke; and their extremities, which have loops wrought in them, are alternately attached to two pins in a roller, round which a cord is wound two or three turns, and passes from thence through rings in the lever, which causes the arbor to revolve, and over a pulley on the arbor to a weight which hangs beside it. When the draught exceeds this weight, it is evident the roller will be drawn round by the traces, and that they will slip off the pins, and be disengaged during the first revolution.

The method of reversing motion by causing pinions to be operated upon by the opposite parts of a face-wheel has been long known and practised by millwrights; and they have various contrivances for performing the alternation, as by levers, screws, tumbling-bobs, &c. One of these will be illustrated by a figure, when we come to the article TIDE-*mill.* And for several methods of reversing motions, see pl. XXXVIII. and XXXIX.

As to the second general method, it has perhaps an appearance of greater simplicity; though, when reduced to practice, it is commonly found more expensive than the former. Suppose that while the horizontal wheel A (fig. 2. pl. XXVIII.) continues to turn always one way, it is required to have the horizontal wheel B turn, sometimes in one direction, and sometimes in another: by means of an additional wheel C, equal in diameter and number of teeth (supposing the velocities in both directions to be equal), this may be accomplished, thus: Let the two wheels B and C have the lower pivots of their axles resting in boxes or cases that may be moved up and down by means of screws; and, while the wheels A and B are nearly of equal thickness, let the wheel C be somewhat more than double the thickness of either: when the motion of the wheel B is to be in a contrary direction to that of A, let the wheel C be lowered so much that its teeth play neither into those of A nor B, while the teeth of A take into those of B and drive it round: when, on the contrary, B is to be moved in the same direction as A, let the wheel B be lowered till its teeth do not come into contact with those of A, and let C be raised until the upper parts of its teeth take between those of the wheel A, while the lower parts of other teeth play into the teeth B; so shall the rotation of B have the direction required. If the motion of the wheel A were sometimes in one direction and sometimes in another, the motion of B might all along be preserved in one direction, by the occasional application of C as an intermediate wheel.

REGULATOR *of descending motions.* See *Hardie's* CRANE, page 173, and *Harriot's Engine*, page 246.

ROTATORY MOTION, when produced by a reciprocating motion, requires some contrivance to render it uniform, or nearly so. The usual method of equalizing is by attaching a fly-wheel to some part of the machinery: but Mr. Arthur Woolf has invented an apparatus to be substituted for the fly in steam engines, which possesses the advantage of equalizing the motion, with the property of being stopped and set to work at any part of the stroke.

Plate XXIII. fig. 4. A represents part of the engine-beam; B the connecting-rod; C the crank-arm; D a cog-wheel, working into another cog-wheel E, of half the size; F a crank-arm on the shaft of the small wheel; G a cylinder closed at bottom, in which a solid or unperforated piston moves, leaving a vacuum beneath. This acts simply instead of weight on the crank F, by the constant pressure of the atmosphere; and the diameter of the piston must be such as nearly to equal one-third of the power of the engine.

In fig. 5. the outer circle is the line described by the crank; the circumference of the inner circle is equal to twice the diameter of the outer, and the square has the same circumference: this last exhibits the inequality still remaining, which by this method is reduced to about one-fifth; but by the assistance of a small fly on the second motion, the effect will become nearly the same as that of a rotative engine with the advantages here mentioned.

The same motion may be applied to a pump, but in this case the two cranks must be horizontal at the same time. (*Nich. Jour.* No. 23. N. S.)

SAWMILLS, constructed for the purpose of sawing either timber or stone, are moved by animals, by water, by wind, or by steam. They may be distinguished into two kinds: those in which the motion of the saws is reciprocating, and those in which the saws have a rotatory motion. In either case the researches of theorists have not yet turned to any account: instead, therefore, of giving any uncertain theory here, we shall proceed to the descriptive part, and refer those who wish to see some curious investigations on this subject to a Memoir on the Action of Saws, by Euler, in Mem. Acad. Roy. Berlin, 1756.

Reciprocating sawmills for cutting timber and moved by water, do not exhibit much variety in their construction. The sawmill represented in pl. XXVIII. is taken from Gray's Experienced Millwright; but it only differs in a few trifling particulars from some which are described in Belidor's Architecture Hydraulique, and in Gallon's Collection of Machines approved by the French Academy.

1. The plate just referred to shows the *elevation* of the mill.

AA the shaft or axle, upon which is fixed the wheel BB (of $17\frac{1}{2}$ or 18 feet diameter), containing 40 buckets to receive the water which impels it round. CC a wheel fixed upon the same shaft containing 96 teeth, to drive the pinion No. 2. having 22 teeth which is fastened upon an iron axle or spindle, having a coupling box on each end that turns the cranks, as DD, round: one end of the pole E is put on the crank, and its other end moves on a joint or iron bolt at F, in the lower end of the frame GG. The crank DD being turned round in the pole E, moves the frames GG up and down, and these having saws in them, by this motion cut the wood. The pinion, No. 2. may work two, three, or more cranks, and thus move as many frames of saws. No. 3, an iron wheel having angular teeth, which one end of the iron K takes hold of, while its other end rolls on a bolt in the lever HH. One end of this lever moves on a bolt at I, the other end may lie in a notch in the frame GG so as to be pushed up and down by it. Thus the catch K pulls the wheel round, while the catch L falls into the teeth and prevents it from going backwards. (See *Universal* LEVER.) Upon the axle of No. 3. is also fixed the pinion No. 4. taking into the teeth in the under edge of the iron bar, that is fastened upon the frame TT, on which the wood to be cut is laid: by this mean the frame TT is moved on its rollers SS, along the fixed frame UU; and of course the wood fastened upon it is brought forward to the saws as they are moved up and down by reason of the turning round of the crank DD. VV, the machine and handle to raise the sluice when the water is to be let upon the wheel BB to give it motion. By pulling the rope at the longer arm of the lever M, the pinion No. 2. is put into the hold or grip of the wheel CC, which drives it; and by pulling the rope R, this pinion is cleared from the wheel. No. 5. a pinion containing 24 teeth, driven by the wheel CC, and having upon its axle a sheave, on which is the rope PP, passing to the sheave No. 6. to turn it round; and upon its axle is fixed the pinion No. 7. acting on the teeth in an iron bar upon the frame TT, to roll that frame backwards when empty. By pulling the rope at the longer arm of the lever N, the pinion No 5. is put into the hold of the wheel CC; and by pulling the rope O it is taken off the hold. No. 8. a wheel fixed upon the axle No. 9. having upon its periphery angular teeth, into which the catch No. 10. takes; and being moved by the lever attached to the upper part of the frame G, it pushes the wheel No. 8. round; and the catch No. 11. falls into the teeth of the wheel, to prevent it from going backwards while the rope rolls in its axle, and drags the logs or pieces of wood in at the door Y, to be laid upon the moveable frames TT, and

carried forward to the saws to be cut. The catches No. 10. 11. are easily thrown out of play when they are not wanted. The gudgeons in the shafts, rounds of the cranks, spindles, and pivots, should all turn round in cods or bushes of brass. Z, a door in one end of the mill-house at which the wood is conveyed out when cut. WW, walls of the mill-house. QQ, the couples or framing of the roof. XXX, &c. windows to admit light to the house.

A plan of this mill is given in pl. 43. of Mr. Gray's book.

2. Sawmills for cutting blocks of stone are generally, though not always, moved horizontally: the horizontal alternate motion may be communicated to one or more saws, by means of a rotatory motion, either by the use of cranks, &c. or in some such way as the following. Let the horizontal wheel ABDC (fig. 3. pl. XX.) drive the pinion *o*PN, this latter carrying a vertical pin P, at the distance of about $\frac{1}{3}$ of the diameter from the centre. This pinion and pin are represented separately in No. 2. of fig. 3. Let the frame WSTV, carrying four saws, marked 1, 2, 3, 4, have wheels V, T, W, W, each running in a groove or rut, whose direction is parallel to the proposed direction of the saws: and let a transverse groove PR, whose length is double the distance of the pin P from the centre of the pinion, be cut in the saw frame to receive that pin. Then, as the great wheel revolves, it drives the pinion, and carries round the pin P: and this pin, being compelled to slide in the straight groove PR, while by the rotation of the pinion on which it is fixed its distance from the great wheel is constantly varying, it causes the whole saw frame to approach to and recede from the great wheel alternately, while the grooves in which the wheels run confine the frame so as to move in the direction T*t*, V*v*. Other blocks of stone may be sawn at the same time by the motion of the great wheel, if other pinions and frames running off in the directions of the respective radii EB, EA, EC, be worked by the teeth at the quadrantal points B, A, and C. And the contrary efforts of these four frames and pinions will tend to soften down the jolts, and equalize the whole motion.

The same contrivance, of a pin fixed at a suitable distance from the centre of a wheel, and sliding in a groove, may serve to convert a reciprocating into a rotatory motion; but it will not be preferable to the common conversion by means of a crank.

3. When saws are used to cut blocks of stone into pieces having cylindrical surfaces, a small addition is made to the apparatus. See figs. 8. 9. pl. XX. The saw, instead of being allowed to fall in a vertical groove as it cuts the block, is at-

tached to a lever or beam FG, sufficiently strong; this lever has several holes pierced through it, and so has the vertical piece ED, which is likewise moveable towards either side of the frame in grooves in the top and bottom pieces AL, DM. Thus, the length KG of the radius can be varied at pleasure, to suit the curvature of NO; and as the saw is moved to and fro by proper machinery, in the direction CB, BC, it works lower and lower into the block, while, being confined by the beam FG, it cuts the cylindrical portion from the block P, as required.

When a completely cylindrical pillar is to be cut out of one block of stone, the first thing will be to ascertain in the block the position of the axis of the cylinder: then lay the block so that such axis shall be parallel to the horizon, and let a cylindrical hole of from one to two inches diameter be bored entirely through it. Let an iron bar, whose diameter is rather less than that of this tube, be put through it, having just room to slide freely to and fro, as occasion may require. Each end of this bar should terminate in a screw, on which a nut and frame may be fastened: the nut frame should carry three flat pieces of wood or iron, each having a slit running along its middle nearly from one end to the other, and a screw and handle must be adapted to each slit: by these means the frame-work at each end of the bar may readily be so adjusted as to form equal isosceles or equilateral triangles; the iron bar will connect two corresponding angles of these triangles, the saw to be used two other corresponding angles, and another bar of iron or of wood the two remaining angles, to give sufficient strength to the whole frame. This construction, it is obvious, will enable the workmen to place the saw at any proposed distance from the hole drilled through the middle of the block; and then, by giving the alternating motion to the saw frame, the cylinder may at length be cut from the block, as required. This method was first pointed out in the Collection of Machines approved by the Paris Academy.

If it were proposed to saw a conic frustum from such a block, then let two frames of wood or iron be fixed to those parallel ends of the block which are intended to coincide with the bases of the frustum, circular grooves being previously cut in these frames to correspond with the circumferences of the two ends of the proposed frustum; the saw being worked in these grooves will manifestly cut the conic surface from the block. This, we believe, is the contrivance of Sir George Wright.

The best method of drilling the hole through the middle of the proposed cylinder seems to be this: on a carriage running upon four low wheels let two vertical pieces (each having a hole just large enough to admit the borer to play freely) be

fixed two or three feet asunder, and so contrived that the pieces and holes to receive the borer may, by screws, &c. be raised or lowered at pleasure, while the borer is prevented from sliding to and fro by shoulders upon its bar, which are larger than the holes in the vertical pieces, and which, as the borer revolves, press against those pieces: let a part of the boring bar between the two vertical pieces be square, and a grooved wheel with a square hole of a suitable size be placed upon this part of the bar; then the rotatory motion may be given to the bar by an endless band which shall pass over this grooved wheel and a wheel of a much larger diameter in the same plane, the latter wheel being turned by a winch handle in the usual way. As the boring proceeds, the carriage with the borer may be brought nearer and nearer the block, by levers and weights, in the same manner as is described under the article *boring of* ORDNANCE.

4. Circular saws, acting not by a reciprocating, but by a rotatory motion, have been long known in Holland, where they are used for cutting wood wanted in veneering. They were introduced into this country, we believe, by General Bentham, and are now used in the dock-yard at Portsmouth, the Royal Arsenal, Woolwich, and in a few other places: but they are not, as yet, so generally adopted as might be wished, considering how well they are calculated to abridge labour, and to accomplish with expedition and accuracy what is very tedious and irksome to perform in the usual way. Circular saws may be made to turn either in horizontal, vertical, or inclined planes; and the timber to be cut may be laid upon a plane inclined in any direction; so that it may be sawn by lines making any angle whatever, or at any proposed distance from each other. When the saw is fixed at a certain angle, and at a certain distance from the edge of the frame, all the pieces will be cut of the same size, without marking upon them by a chalked line, merely by causing them to be moved along and keeping one side in contact with the side of the frame; for then, as they are brought one by one to touch the saw revolving on its axle, and are pressed upon it, they are soon cut through.

Mr. Smart, of Ordnance Wharf, Westminster-bridge, has several circular saws, all worked by a horse in a moderate sized walk; one of these, intended for cutting and boring tenons used in this gentleman's hollow masts, is represented in fig. 2. pl. XXVI. NOPQR is a hollow frame, under which is part of the wheel-work of the horse-mill.—A, B, D, C, E, F, are pulleys, over which pass straps or endless bands, the parts of which out of sight run upon the rim of a large vertical wheel: by means of this simple apparatus, the saws s, s', are made to revolve upon their axles with an equal velocity, the same band

passing round the pulleys D, C, upon those axles; and the rotatory motion is given to the borer G by the band passing over the pulley A. The board I is inclined to the horizon in an angle of about 20 degrees: the plane of the saw S′ is parallel to that of the board I, and about $\frac{1}{4}$ of an inch distant from it, while the plane of the saw S is vertical, and its lowest point at the same distance from the board I. Each piece of wood K out of which the tenon is to be cut is 4 inches long, an inch and a quarter broad, and $\frac{5}{8}$ of an inch thick. One end of such piece is laid so as to slide along the ledge at the lower part of the board I; and as it is pushed on, by means of the handle H, it is first cut by the saw S′, and immediately after by the saw S: after this the other end is put lowest, and the piece is again cut by both saws: then the tenon is applied to the borer G, and as soon as a hole is pierced through it, it is dropped into the box beneath. By this process, at least 30 tenons may be completed in a minute, with greater accuracy than a man could make *one* in a quarter of an hour, with a common hand-saw and gimblet. The like kind of contrivance may, by slight alterations, be fitted for many other purposes, particularly all such as may require the speedy sawing of a great number of pieces into exactly the same size and shape. A very great advantage attending this sort of machinery is, that, when once the position of the saws and frame is adjusted, a common labourer may perform the business just as well as the best workman.

Mr. Brunel, a well-known civil engineer, took out a patent for saw machinery, in May, 1805. The following is an abridgement of his specification. The saws are circular, and turn upon an axis passing through their centre. When they are too large to be made with sufficient strength of only one piece of steel, they may be constituted of two, four, eight, &c. pieces, and the joining edge of one plate must be hollow, to receive the sharp edge of that which is to be fitted into it. To augment the strength of the plates, flanches may be closely fitted to them, several pieces of leather or of paper being interposed, by means of which and screws duly applied, the whole may be made very firm and strong.

The improvements in the machinery for sawing timber easily and expeditiously consist in the modes of laying and holding the piece of wood in the carriage or drag, in the facility of shifting the saw from one cut to another, and in the practicability of sawing both ways either towards or from the saw or saws.

Each circular saw is adjusted upon a cylindrical spindle, which turns within rodings; the motion being communicated by means of a strap or band turning about a proper drum-

wheel, and moved by any of the usual actuating powers, as wind, water, steam, animals, &c. The piece of timber being placed upon a drag or carriage, is held fast by means of clamps; and the carriage is moved towards and from the saw by a handle or crank communicating, by the assistance of cog wheels, to a pinion which engages in a horizontal rack running under the frame of the carriage. This carriage is furnished with rollers serving to ease its longitudinal motion, and is intended to be moved by hand, so that its velocity may be varied at pleasure: the length of this carriage must obviously be proportionate to the size of the timber generally cut by the saw.

After the saw has performed one cut, instead of moving the timber, the saw itself is moved sidewise, that is, in the direction of its axle, by means of screws, after a method which may be easily conceived, till it is brought to the proper position for the next cut; when an adjusting or fixing screw prevents any lateral motion, and the rotary motion of the saw, and the rectilinear motion of the wood, may be resumed.

Circular wedges are used, being intended to revolve by the motion of the log to follow the cut opened by the saw, and by that means to ease the friction, and steady the piece of timber. Sometimes an instrument composed of several parallel plates of metal may be employed instead of the circular wedges.

When several saws are adjusted on one spindle, a piece of timber may be converted into planks by being drawn once through under the saws. In that case the flanches of the saws are fixed upon an iron drum, and kept firmly in their relative parallel positions by four bolts. In order to lower the saws as they wear away, the side rails sustaining their axles may be depressed by means of wedges. The log of wood is not to lie close upon the carriage or drag, but upon some transverse pieces, which may be moved if requisite when they come near the saw.

Some very complete and extensive saw-mills have been erected by Mr. Brunel, in the Carriage Department of the Royal Arsenal, Woolwich, under the superintendence of Major Generals Cuppage and Miller.

Among the numerous purposes for which saws are employed, is that of cutting off the tops of piles. When these are below water, some additional mechanism is necessary to cause the saws to work in a horizontal plane at a suitable depth. Different contrivances for this purpose, with illustrative engravings, are described by M. Hachette, *Traité des Machines*, p. 252—275.

SCAPEMENT, from the French word *echappement*, a term

used among clock and watch-makers, to denote the general contrivance by which the pressure of the wheels, which move always in one direction, and the reciprocating motion of the pendulum or balance, are accommodated the one to the other. When a tooth of a wheel has given the balance or pendulum a motion in one direction, it must quit it, that it may get an impulsion in the opposite direction; and it is this *escaping* of the tooth of the wheel from the balance or pendulum, or of the latter from the former, whichever we please to call it, that has given rise to the general term.

From the nature of a pendulum, it follows, that it need only to be removed from the vertical, and then let go, in order to vibrate and measure time. Hence it might seem that nothing is wanted but a machinery so connected with the pendulum as to keep a register, as it were, of the vibration. It could not be difficult to contrive a method of doing this; but more is wanted: the air must be displaced by the pendulum. This requires some force, and must therefore employ some part of the momentum of the pendulum. The pivot on which it swings occasions friction—the thread, or thin piece of metal by which it is hung, in order to avoid this friction, occasions some expenditure of force by its want of perfect flexibility or elasticity. These, and other causes, make the vibrations become more and more narrow by degrees, till at last the pendulum is brought to rest. We must, of course, have a contrivance in the wheelwork which will restore to the pendulum the small portion of force which it loses in every vibration. The action of the wheels therefore may be called a *maintaining power*, because it keeps up the vibrations. But this may affect the regularity of vibration. If it be supposed that the action of gravity renders all the vibrations isochronous, we must grant that the additional impulsion by the wheels will destroy that isochronism, unless it be so applied that the sum total of this impulsion and the force of gravity may vary so with the situation of the pendulum as still to give a series of forces, or a law of variation, perfectly similar to that of gravity. This cannot be effected, unless we know both the law which regulates the action of gravity, producing isochronism of vibration, and the intensity of the force to be derived from the wheels in every situation of the pendulum.

Thus it appears that considerable scientific skill as well as mechanical ingenuity may be displayed in the construction of scapements; and the judicious consideration of them becomes of great importance to the artist: yet, notwithstanding this, no material improvement was made in them from the first application of the pendulum to clocks till the days of Mr. George

Graham; nothing more was attempted before his time than to apply the impulse of the swing-wheel, in such manner as was attended with the least friction, and would give the greatest motion to the pendulum. Dr. Halley discovered, by some experiments made at the Royal Observatory at Greenwich, that by adding more weight to the pendulum it was made to vibrate larger arcs, and the clock went faster; by diminishing the weight of the pendulum, the vibrations became shorter, and the clock went slower: the result of these experiments being diametrically opposite to what ought to be expected from the theory of the pendulum, probably first roused the attention of Mr. Graham, who was not only skilful in practice, but had much mathematical knowledge, and was well qualified to examine the subject scientifically: he soon made such further trials as convinced him, that this seeming paradox was occasioned by the retrograde motion, which was given to the swing-wheel by every construction of scapement that was at that time in use; and his great sagacity soon produced a remedy for this defect, by constructing a scapement which prevented all recoil of the wheels, and restored to the clock pendulum, wholly in theory, and nearly in practice, all its natural properties in its detached simple state. This scapement, with a few others of the most approved construction, will now be briefly described.

1. The scapement which has been in use for clocks and watches ever since their first appearance in Europe is extremely simple; and its mode of operation is too obvious to need much explanation. In fig. 1. pl. XXIX. XY represents a horizontal axis, to which the pendulum P is attached by a slender rod, or otherwise. This axis has two leaves C and D attached, one near each end, and not in the same plane, but so that when the pendulum hangs perpendicularly, and at rest, the piece C inclines a few degrees to the right hand, and D as much to the left. They commonly make an angle of from 70 to 90 degrees: they are called by the name of *pallets*. AFB represents a wheel turning round on a perpendicular axis EO, in the order of the letters AFEB. The teeth of this wheel are cut into the form of the teeth of a saw, leaning forward, in the direction of the motion of the rim. As they somewhat resemble the points of an old-fashioned royal diadem, this wheel has got the name of the *crown-wheel*. In watches it is often called the *balance-wheel*. The number of the teeth is generally odd; so that when one of them B is pressing on a pallet D, the opposite pallet C is in the space between two teeth A and I. The figure represents the pendulum at the extremity of its excursion to the right hand, the tooth A having just escaped from the pal-

let C, and the tooth B having just dropped on the pallet D. It is plain, that as the pendulum now moves over to the left, in the arch PG, the tooth B continues to press on the pallet D, and thus accelerates the pendulum, both during its descent along the arch PH, and its ascent along the arch HG. It is no less evident, that when the pallet D, by turning round the axis XY, raises its point above the plane of the wheel, the tooth B escapes from it, and I drops on the pallet C, which is now nearly perpendicular. I presses C to the right, and accelerates the motion of the pendulum along the arch GP. Nothing can be more obvious than this action of the wheel in maintaining the vibrations of the pendulum. We can easily perceive, also, that when the pendulum is hanging perpendicularly in the line XH, the tooth B, by pressing on the pallet D, will force the pendulum a little way to the left of the perpendicular, and will force it so much the further as the pendulum is lighter; and, if it be sufficiently light, it will be forced so far from the perpendicular that the tooth B will escape, and then I will catch on C, and force the pendulum back to P, where the whole operation will be repeated. The same effect will be produced in a more remarkable degree, if the rod of the pendulum be continued through the axis XY, and a ball Q put on the other end to balance P. And, indeed, this is the contrivance which was first applied to clocks all over Europe, before the application of the pendulum. They were *balance* clocks. The force of the wheel was of a certain magnitude, and therefore able, during its action on a pallet, to communicate a certain quantity of motion and velocity to the balls of the balance. When the tooth B escapes from the pallet D, the balls are then moving with a certain velocity and momentum. In this condition, the balance is checked by the tooth I catching on the pallet C. But it is not instantly stopped. It continues its motion a little to the left, and the pallet C forces the tooth I a little backward. But it cannot force it so far as to escape over the top of the tooth I; because all the momentum of the balance was generated by the force of the tooth B: and the tooth I is equally powerful. Besides, when I catches on C, and C continues its motion to the left, its lower point applies to the face of the tooth I, which now acts on the balance by a long and powerful lever, and soon stops its further motion in that direction; and now, continuing to press on C, it urges the balance in the opposite direction. Thus we see that in a scapement of this kind the motion of the wheel must be very hobbling and unequal, making a great step forward, and a short step backward, at every beat. This has occasioned the contrivance to get the name of the *recoiling scapement*, or the *scapement of recoil*.

In this scapement the vibrations are quicker than if the balance or pendulum vibrated freely: for the recoil shortens the ascending part of the vibration, by contracting the extent of the arc, and the re-action of the wheel accelerates the descending part of the vibration. In this scapement, too, if the maintaining power be increased, the vibration will be performed in larger arcs, but in less time: because the greater pressure of the crown-wheel on the pallet will cause the balance to vibrate through larger arches; and the time will be less increased on this account than it will be diminished by the acceleration that pressure gives to the balance and the diminution of the time of recoil.

2. The preceding scapement not being well adapted to such vibrations as are performed through arcs of a few degrees only, another construction has been made which has been in constant use for about a century in clocks, with a long pendulum beating seconds. In fig. 2. AB represents a vertical wheel called the swing-wheel, having thirty teeth. CD represents a pair of pallets connected together, and moveable in conjunction with the pendulum on the centre or axis F. One tooth of the wheel, as shown in the figure, rests on the inclined surface of the inner part of the pallet C; on which its disposition to slide tends to throw the point of the pallet further from the centre of the wheel, and consequently assists the vibration in that direction. While the pallet C moves outwards and the wheel advances, the point of the pallet D of course approaches towards the centre in the opening between the two nearest teeth; and when the acting tooth of the wheel slips off, or escapes from the pallet C, another tooth on the opposite side immediately falls on the exterior inclined face of D, and by a similar operation tends to push that pallet from the centre. The returning vibration is thus assisted by the wheel, while the pallet C moves towards the centre, and receives the succeeding tooth of the wheel, after the escape from the point of D. Thus may the alternation be conceived to go on without limit.

In this scapement, as well as the former, the vibrating part is constantly under the influence of the maintaining power, except during the interval of the drop, or actual escape of the wheel from one pallet to the other. One principal recommendation of this scapement seems to have been the facility with which it affords an index for seconds in the face of the clock. Though the pendulum, according to this construction, is constantly connected with the maintaining power in a clock, yet the variations of that power have not the same mischievous effect as in a watch, because the momentum of the pendulum, compared with the impulse of the maintaining power, is prodigiously greater in the former of these instruments. A very

considerable change in the maintaining power of a clock with a long pendulum will only cause a variation of a few seconds in the daily rate.

3. Mr. Graham's scapement, already spoken of, was a considerable improvement upon that just described. He took off part of the slope furthest from the points of the pallets; and instead of that part he formed a circular or cylindrical face, having its axis in the centre of motion. Pallets of this kind are shown at the lower part of fig. 2. at E and G, having H for their centre or axis. A tooth of the wheel is seen resting upon the circular inner surface of the pallet G. which therefore is not affected by the wheel, excepting so far as its motion, arising from any other cause, may be affected by the friction of the tooth; and this resistance is exceedingly minute, not amounting to one-eighth of the pressure on the arch. Nay, we think it appears from the experiments of Coulomb, that, in the case of such minute pressure on a surface covered with oil, there is no sensible retardation analogous to that produced by friction, and that what retardation we observe arises entirely from the clamminess of the oil. If the vibration of the pendulum be supposed to carry G outwards, the slope surface will be brought to the point of the tooth, which will slide along it, and urge the pallet outwards during this sliding action. When the tooth has fallen from the point of this pallet, an opposite tooth will be received on the circular surface of E, and will not affect the variation, excepting when the slope surface of E is carried out so as to suffer the tooth to slide along it. This contrivance is known by the name of the *dead beat*, the *dead scapement;* because the seconds index stands still after each drop, whereas the index of a clock with a recoiling scapement is always in motion, hobbling backward and forward.

In this scapement, an increase of the maintaining power renders the vibrations larger and slower: because the greater pressure of the tooth on the edge of the pallet throws it round through a greater arch; and its increased pressure on both surfaces of the pallet retards its motion.

4. The effect of the scapement which has been called horizontal, because the last wheel in watches of this construction has its plane parallel to the rest of the system, is similar to that of the dead beat scapement of Graham. In fig. 5, the horizontal wheel is seen with twelve teeth, upon each of which is fixed a small wedge supported above the plane of the wheel, as may be seen at the letters A and B. On the verge of the balance there is fixed part of a hollow cylinder of steel or other hard material, the imaginary axis of which passes through the pivots of the verge. C represents this cylindrical piece, into

which the verge D may be supposed to have fallen. While the vibration causes the cylindrical piece to revolve in the direction which carries its anterior edge towards the axis of the wheel, the point of the wedge will merely rub the internal surface, and no otherwise affect the vibration of the balance than by retarding its motion. But when the return of the vibration clears the cylinder of the point of the wedge D, the wheel will advance, and the slope surface of the wedge acting against the edge of the cylinder will assist the vibration of the balance When the edge of the cylinder arrives at the outer point of the wedge D, its posterior edge must arrive at the position denoted by the dotted lines of continuation; immediately after which the wedge or tooth E will arrive at the position *e*, and rest on the outer surface of the cylinder, where it will produce no other effect than that of retardation from friction, as was remarked with regard to the wedge D. until the course of the vibration shall bring the posterior edge of the cylinder clear of the point of the wedge. In this last situation, the wedge will act on the edge of the cylinder, and assist the vibration, as in the former case, until that edge shall arrive at the outer or posterior point of the wedge; immediately after which the leading point will fall on the inner surface of the cylinder in the first position, as was shown in the wedge D.

Horizontal watches were greatly esteemed for a considerable time, until lately, when they gave place to those constructions which are known by the name of detached or free scapements. In the common scapement, fig. 1, an increase of the maintaining power increases the recoil, and accelerates the vibrations: but with the horizontal scapement there is no recoil; and an increase of the maintaining power, though it may enlarge the arc of vibration, will not necessarily diminish or alter the time. It is accordingly found, that the experiment of altering the maintaining power by the application of the key does not alter the rate in the same perceptible manner as in common watches.

5. Fig. 6, represents the free scapement of our best portable time-pieces. Fig. 4, exhibits the scapement on a large scale. On the verge of the balance is fixed a circular piece of sapphire, or of hard steel, EL, out of which a sectoral piece is cut. HG is a straight spring fixed near its extremity H, and having at the other extremity a pin G, against which one of the teeth of the wheel D rests when the train is at rest. This spring has a slight tendency towards the centre of the wheel, but is prevented by the stop K from throwing the pin further inwards than just to receive the point of the tooth. I is a very slender spring fixed at the end I, and pressing very slightly against the pin G, in a di-

rection tending to throw it from the wheel D, but which on account of the greater power of HG it cannot effect. It may be observed that the spring I proceeds a little beyond the pin G.—F is a lever proceeding from the verge of the balance directly opposte the end of the spring I, and long enough to strike it in its vibration. The action is as follows:—From the pressure of the main spring the wheel (fig. 4.) is urged from D towards F, but is prevented from moving by the pin G. Let the balance be made to vibrate, and the lever F will move through the arc F*f*, strike the inner extremity of the spring I, and displace the pin G. At this instant the face E, which may be called the pallet, will have arrived at the position *e*, against which the tooth of the wheel will fall, and communicate its impulse through about 15° or 16° of the vibration. But F quits the spring I sooner than the wheel quits the pallet E, and consequently the pin G will have returned to its first station before the wheel can have advanced a whole tooth, and the spring or detent HG will receive the wheel as before, immediately after its escape from the pallet. The returning vibration of the balance will be made with the piece EL perfectly at liberty between two teeth of the wheel, as in the sketch, and the back stroke of the lever F against the tender spring I will have no effect whatever on the pin G; this spring being like the back spring of the jacks of the harpsichord, active in one direction only. The third vibration of the balance will unlock the detent as before; the impulse will again be given, and the whole process will be repeated: and in this manner, the balance, though it may vibrate through the greatest part of the entire circle, will be entirely free of the works, except during the very small time of the drop of the wheel.

It is hardly necessary to make any remark on this scapement. It requires little or no oil; and when all the parts, particularly the pendulum spring, are duly adjusted, it is found that a very great variation in the first mover will remarkably alter the arc of vibration without affecting the rate. The piece EL might have consisted of a single pallet or arm, instead of a portion of a circle or cylinder; but such a piece would have been rather less convenient to make in sapphire, or ruby, as in the best time-pieces, and would also have been less useful. For if by any accident or shock the pin G should be displaced for an instant, the wheel D will not run down, because it will be caught upon the circular surface of EL. It is indeed very easy to observe, that the piece EL would operate without the detent, though with much friction during the time of repose. The tooth of the wheel would in that case rest upon its circular face.

6. In the two last scapements we have seen the variable effects of the maintaining power almost entirely removed, as far as can be practically discerned. Fig. 7, exhibits the scapement of Mudge; in which the balance is perfectly detached from the train of wheels, except during the extremely short interval of striking out the parts which serve the purpose of detents. ONEBQ is the circumference of the balance, vibrating by the action of a spiral spring as usual on its axis CA DH passing through the centre C: the axis is bent into a crank, AXYD, to make room for the other work. LM, ZW, are two rods fixed to the crank at the points L and Z, parallel to XY. *c d e f r s* are fixed parts of the machine. TR is an axis concentric with that of the balance, and carrying an arm G*o* nearly at right angles to it, and a small auxiliary spring *u*, which is wound up whenever the arm G*o* is moved in the direction *oh*. *p* is a curved pallet fixed to the axis TR, which receives the tooth of the balance wheel near the axis. The tooth, proceeding along the curved surface, by the force of the main spring turns the axis and its arm G*o*, and winds up the spring *u*. A small projection at the extremity of the curved surface of the pallet *p* prevents the further progress of the tooth, when the arm *o*G has been turned through an arc *oh*, of about 27°; and consequently the spring *u* has been wound up through the same angle or arc, $oGh = 27°$.——FS is another axis exactly similar to TR. It carries its arm I*o*, and spring *v*, and the tooth of the balance-wheel *lm* winds up the spring *v*, by acting on the pallet *q*, and is detained by a projection, after having carried it through an angle of 27°, exactly as in the former case. The arcs passed through by the arms G*o* and I*o*, and marked in the figure, are also denoted by the same letters on the rim of the balance.

The effect of this scapement may be thus explained: let the balance be in the quiescent state, the main spring being unwound, and the branch or crank in the position represented in the figure. If the quiescent points of the auxiliary springs coincide with that of the balance-spring, the arm G*o* will just touch the rod LM, and in like manner the arm I*o* will just touch the rod WZ; the two arms G*o* and I*o* in this position are parallel to the line CO. This position of the balance and auxiliary springs remains as long as the main spring of the machine continues unwound; but whenever the action of the main spring sets the balance-wheel in motion, a tooth thereof meeting with one or other of the pallets *p* or *q*, will wind up one of the auxiliary springs: suppose it should be the spring *u*. The arm G*o* being carried into the position G*h*, by the force of the balance-wheel acting on the pallet *p*, remains in that position

as long as the tooth of the balance-wheel continues locked by the projection at the extremity of the pallet *p*; and the balance itself not being at all affected by the motion of the arm GO, nor by the winding up of the spring *u*, remains in its quiescent position: consequently no vibration can take place, except by the assistance of some external force to set the balance in motion. Suppose an impulse to be given sufficient to carry it through the semi-arc O B, which is about 135° in Mr. Mudge's construction.

The balance, during this motion, carries with it the crank AXYD, and the affixed rods LM, ZW. When the balance has described an angle of about 27° = the angle *och*, or *oGh*, the rod LM meets with the arm GH, and by turning the axis TR, and the pallet *p* in the direction of the arc *oh*, releases the tooth of the balance-wheel from the projection at the extremity of the pallet *p*: the balance-wheel immediately revolves, and the lower tooth meeting with the pallet *q*, winds up the auxiliary spring *v*, and carries the arm I*o* with a circular motion through the angle *oIk*, about 27°, in which position the arm I*o* remains as long as the tooth of the balance-wheel is locked by the pallet *q*. While the spring *v* is winding up through the arc *ok*, the balance describes the remaining part of the semi-arc *h*B, and during this motion the rod LM carries round the arm G*h*, causing it to describe an angle *h*CB, or *h*GB, which is measured by the arc *h*B = 108°. When the balance has arrived at the extremity of the semi-arc OB = 135°, the auxiliary spring *u* will have been wound up through the same angle of 130°, that is to say, 27°, by the force of the main-spring acting on the pallet *p*, and 108° by the balance itself, carrying along with it the arm G*o*, or G*h*, while it describes the arc *h*B. The balance therefore returns through the arc BO, by the joint action of the balance-spring and the auxiliary spring *u*; the acceleration of both springs ceasing the instant the balance arrives at the quiescent point *o*. When the balance has proceeded in its vibration about 27° beyond the point O, to the position C*k*, the rod ZW meets with the arm I*k*, and by carrying it forward releases the tooth of the balance-wheel from the pallet *q*. The balance-wheel accordingly revolves, and the upper tooth meeting with the pallet *p* winds up the auxiliary spring *u* as before. The balance with the crank proceeding to describe the remaining semi-arc *k*E, winds up the spring *v* through the further angle *k*CE = 108°, and returns through the semi-arc E*o*, by the joint action of the balance-spring and the auxiliary spring *v*, both of which cease to accelerate the balance the instant it has arrived at O.

It may be remarked, in this curious scapement, that the

motion of the balance in its semi-vibration from the point of quiescence is opposed through an arc of no more than 108°, but is accelerated in its return through the whole arc of 135°, and that the difference is what maintains the vibrations; and moreover, that the force from the wheel being exerted to wind up each auxiliary spring during the time it is totally disengaged from the balance, this last organ cannot be affected by its irregularities, except so far as they may render it more difficult to disengage the rim of the pallet from the tooth. The balance describes an arc of about 8° during this disengagement.

Count Bruhl, in his pamphlet "On the Investigation of Astronomical Circles," after describing Mudge's scapement, proceeds thus: "By what has been said, it is evident, that whatever inequality there may be in the power derived from the main-spring (provided the latter be sufficient to wind up those little pallet-springs), it can never interfere with the regularity of the balance's motion, but at the instant of unlocking the pallets, which is so instantaneous an operation, and the resistance so exceedingly small, that it cannot possibly amount to any sensible error. The removal of this great obstacle was certainly never so effectually done by any other contrivance, and deserves the highest commendation, as a probable means to perfect a portable machine that will measure time correctly. But this is not the only, nor indeed the principal, advantage which this time-keeper will possess over any other; for, as it is impossible to reduce friction to so small a quantity as not to affect the motion of a balance, the consequence of which is, that it describes sometimes greater and sometimes smaller arcs, it became necessary to think of some method by which the balance might be brought to describe those different arcs in the same time. If a balance could be made to vibrate without friction or resistance from the medium in which it moves, the mere expanding and contracting of the pendulum-spring would probably produce the so much wished for effect, as its force is supposed to be proportional to the arcs described; but as there is no machine void of friction, and as from that cause the velocity of every balance decreases more rapidly than the spaces gone through decrease, this inequality could only be removed by a force acting on the balance, which assuming different ratios in its different stages, could counterbalance that inequality. This very material and important remedy, Mr. Mudge has effected by the construction of his scapement; for his pallet-springs having a force capable of being increased almost at pleasure, at the commencement of every vibration, the proportion in their different degrees of tension may be altered till

it answers the intended purpose. This shows how effectually Mr. Mudge's scapement removes the two greatest difficulties that have hitherto baffled the attempts of every other artist, namely, the inequalities of the power derived from the main spring, and the irregularities arising from friction, and the variable resistance of the medium in which the balance moves."

7. Fig. 8, is the sketch of an adaptation of Mudge's scapement to a clock. LM is a part of the periphery of the wheel. GA, GB, are two arms separately moveable on the same axis, and terminating in the pallets A, B. These pallets have inclined faces, with a claw or detent at the lower part of each. GO, IO, are tails proceeding from each pallet-piece respectively, and the dark spot at N represents a pin proceeding from the pendulum rod, and capable of moving either of the tails according to the course of the vibration. The dotted circles *u* and *v* represent weights which are stuck upon two pins, and may be changed for others, greater or smaller, until the most suitable quantity is found. Suppose the wheel to be urged from L towards M, and the pendulum made to vibrate by external impulse. The pin N proceeding towards L will strike the tail GO, raise the pallet A, and set the wheel at liberty: which sliding along the inner surface of the pallet B, will raise it, and stop against the claw at its lower end. IO will consequently be carried into the position IP; and the pallet A in its return will be opposite to a vacancy, which will permit the tail GO to follow the pin N as far as the perpendicular situation. The pendulum will therefore be assisted by the weight *u* through a longer arc in its descent, than it was impeded by it in its ascent. In the opposite semi-vibration toward M, the pendulum will proceed unopposed by *v*, while it passes through the angle OIP, when it will raise B, and permit the wheel to elevate the pallet A. In the motion on this side of the perpendicular, it is also clear that the descent will be more assisted than the ascent was impeded. Whence it follows, that the clock will continue to go: and no variation of the force of the wheel LM, which raises the pallets in the absence of the pendulum, will affect the vibration, except so far as it may afford a variable resistance at the detent or claw.

8. Mr. Mudge has also given another detached scapement, which he recommends for pocket-watches, and executed entirely to his satisfaction in one made for the queen. A dead-beat pendulum scapement is interposed between the wheels and the balance. The crutch EDF (fig. 3.) has a third arm DG standing outwards from the meeting of the other two, and of twice their length. This arm terminates in a fork AGB. The verge V has a pallet C, which, when all is at rest, would stand between the points A, B, of the fork. But the wheel, by its action on

the pallet E, forces the fork into the position B*gb*, the point A of the fork being now where B was before, just touching the cylindrical surface of the verge. The scapement of the crutch EDF is not accurately a dead-beat scapement, but has a very small recoil beyond the angle of impulsion. By this circumstance the branch A (now at B) is made to press most gently on the cylinder, and keeps the wheel locked, while the balance is going round in the direction BHA. The point A gets a motion from A to B by means of a notch in the cylinder, which turns round at the same time by the action of the branch AG on the pallet C; but A does not touch the cylinder during this motion, the notch leaving free room for its passage. When the balance returns from its excursion, the pallet C strikes on the branch A (still at B), and unlocks the wheel. This now acting on the crutch-pallet F, causes the branch *b* of the fork to follow the pallet C, and give it a strong impulse in the direction in which it is then moving, causing the balance to make a semi-vibration in the direction AHB. The fork is now in the situation A*ga*, similar to B*gb*, and the wheel is again locked on the crutch-pallet E.

The intelligent reader will admit this to be a very steady and effective scapement. The lockage of the wheel is procured in a very ingenious manner; and the friction on the cylinder, necessary for effecting this, may be made as small as we please, notwithstanding a very strong action of the wheel; for the pressure of the fork on the cylinder depends entirely on the degree of recoil that is formed on the pallets E and F. *Pressure* on the cylinder is not indispensably necessary, and the crutch-scapement may be a real dead-beat. But a small recoil, by keeping the fork in contact with the cylinder, gives the most perfect steadiness to the motion. The ingenious inventor, a man of approved integrity and judgment, declares that her majesty's watch was the best pocket-watch he had ever seen. We are not disposed to question its excellency.

9. Another scapement, in which a considerable degree of ingenuity is united with comparative simplicity, is that of Mr. De Lafons. The inventor's description, and some of his observations, as presented to the Society of Arts, are as follows:

"Although the giving an equal impulse to the balance has been already most ingeniously done by Mr. Mudge and Mr. Haley (from whose great merit I would not wish to detract), yet the extreme difficulty and expense attending the first, and the very compound locking of the second, render them far from completing the desired object.

"The perfections and advantages arising from my improvements on the remontoire detached scapement for chronometers,

which gives a perfectly equal impulse to the balance, and not only entirely removes whatever irregularities arise from the different states of fluidity in the oil, from the train of wheels, or from the main spring, but does it in a simpler way than any with which I am acquainted. I trust it will not be thought improper in me to answer some objections made at the examinations before the committee, as I am fully persuaded the more mathematically and critically the improvements are investigated, the more perfect they will prove to be.

"It was first observed, that my method did not so completely detach the train of wheels from the balance as another scapement then referred to. I beg leave to remark, that the train of wheels in mine is prevented from pressing against the locking by the whole power of the remointoire-spring; so that the balance has only to remove the small remaining pressure, which does away that objection, and also that of the disadvantage of detents, as this locking may be compared to a light balance turning on fine pivots, without a pendulum-spring; and has only the advantage of banking safe at two turns of the balance, and of being firmer and less liable to be out of repair than any locking where spring-work is used, but likewise of unlocking with much less power.—It was then observed, it required more power to make it go than usual. Permit me to say, it requires no more power than any other remontoire-scapement, as the power is applied in the most mechanical manner possible.—And, lastly, it was said, that it set or required the balance to vibrate an unusually large arc before the piece would go. This depends on the accuracy of the execution, the proportionate diameter and weight of the balance, the strength of the remontoire-spring, and the length of the pallets. If these circumstances are well attended to, it will set but little more than the most generally detached scapements."

A, shows the scape-wheel; pl. XXIX.

B, the lever-pallet, on an arbor with fine pivots, having at the lower end

C, the remontoire or spiral-spring fixed with a collar and stud, as pendulum-springs are.

D, the pallet of the verge, having a roller turning in small pivots for the lever-pallet to act against.

E, Pallets to discharge the locking, with a roller between, as in fig. 10.

F, the arm of the locking-pallet continued at the other end to make it poise, having studs and screws to adjust and bank the quantity of motion.

a and *b*, the locking-pallets being portions of circles, fastened on an arbor turning on fine pivots.

G, the triple fork, at the end of the arm of the locking pallets.

The centre of the lever-pallet in the draft is in a right line between the centre of the scape-wheel and the centre of the verge, though in the model it is not: but may be made so or not, as best suits the calliper, &c.

"The scape-wheel A, with the tooth 1, is acting on the lever-pallet B, and has wound up the spring C: the verge-pallet D (turning the way represented by the arrow) the moment it comes within the reach of the lever-pallet, the discharging pallet E, taking hold of one prong of the fork, removes the arm F, and relieves the tooth 3 from the convex part of the lock *a*. The wheel goes forward a little, just sufficient to permit the lever-pallet to pass, while the other end gives the impulse to the balance: the tooth 4 of the wheel is then locked on the concave side of the lock *b*, and the lever-pallet is stopped against the tooth 5, as in fig. 11. So far the operation of giving the impulse, in order again to wind the remointoire-spring (the other pallet at E, in the return, removing the arm F the contrary direction), relieves the tooth 3 from the lock *b*. The wheel again goes forward, almost the whole space, from tooth to tooth, winds the spiral spring again, and comes into the situation of fig. 1, and thus the whole performance is completed. The end of the lower pallet B resting on the point of the tooth 1, prevents the wheel exerting its full force on the lock *a*, as in fig. 1. The same effect is produced by the pallet lying on the tooth 5, by preventing the wheel from pressing on *b*; and thus the locking becomes the tightest possible. This scapement may be much simplified by putting a spring with a pallet made in it, as in fig. 12, instead of the lever-pallet, and spiral-spring. The operation will be in other respects exactly the same, avoiding the friction of the pivots of the lever-pallet. This method I prefer for a piece to be in a state of rest, as a clock; but the disadvantage, from the weight of the spring in different positions, is obvious. The locking may be on any two teeth of the wheel, as may be found most convenient."

Many other ingenious scapements have been contrived by Harrison, Hindley, Ellicott, Lepaute, Le Roy, Berthoud, Arnold, Whitehurst, Earnshaw, Nicholson, &c. But descriptions of them would extend this article to much too great a length. What is here collected will, we trust, furnish some insight into the nature of a few of the most approved scapements.

SCREW, MACHINE FOR MAKING. Mr. Angus Mackinnon, of Glasgow, has invented a machine for this purpose, of which he has published the following description in the *Glasgow Mechanics' Magazine*.

Fig. 9, is a plan, and fig. 10, is an end view of the machine for constructing the screw.

AA is the cast iron bar, upon which the die frame, BB, is made to move. *c c c c*, two strong springs, attached to the die-frame, having rollers, *d d d d*, on each end, moving upon the angular parallel edges of the bar AA. E is a frame for holding the cutter; the cover being removed to show the action of the cutter upon the steel cylinder, of which the screw is made. F, the steel cylinder; the point of the cutter (which must be adjusted to an angle, varying according to the pitch of thread wanted) is seen projecting from the frame E, being pressed forward by the screw G. One end of the cylinder F, acts upon the centre in the head-stock I. The journal upon the other end of the cylinder works into the steel collar V. *k k k k*, four small screws for pressing forward the springs *c c c c*. *l l l l*, four small eyes in the die-frame, to which cords are attached, passing over the pulleys *m m m m*; weights being hooked on at the other ends of the cords, sufficient to overcome the friction of the die-frame. N, the handle to turn the cylinder.

In the beginning to make the screw, the two weights to the left are hooked on to the ends of the cords, and the cylinder is turned round by the handle, until the cutter traverses the length of the cylinder, when the weights are removed to the cords on the right hand. By continuing this operation alternately from right to left, an original and perfect screw is produced, as exhibited in fig. 11. In the end view of the machine, fig. 10, *o o* represents one of the feet by which it is fastened to the bench.

The same letters refer to the same parts of the machine in both figures where those parts are exhibited.

Having obtained, as already described, one screwed cylinder; this is removed, and another of the same size is put into the machine. The same operation is performed on it as on the last; but it is not screwed to a full thread, the sharp cutter being removed when the spaces and threads are of an equal size, and a square cutter is put in its place, by means of which is obtained what is technically termed a square thread, as shown in fig. 12. In the same manner, a third and a fourth cylinder are screwed, each being successively a degree smaller than the preceding.

The small frame holding the cutter is now removed, and replaced with dies, a set of which is to be screwed with each of the above cylinders. When the dies are to be screwed, they are placed in the die-frame with one of the cylinders already made, and pressed against it by the screws G, *g*, until they are fully screwed. After this they are replaced with another

cylinder, and another set of dies which are likewise to be screwed. The same operation is performed with a third and a fourth set; (the first set of dies *only*, having a sharp thread, the other set having square threads); after which they are to be tempered. The head stock is now removed to the left, to admit the cylinder of which the perfect screw is to be made, and fastened at any required distance, the machine being constructed to cut a screw above three feet in length.

The cylinder being placed between the sharp dies, which are gently pressed by the screws G, *g*, is turned round by the handle, until the die-frame reaches the left hand of the cylinder; it is then turned in the contrary way, and worked in the same manner as when using the cutter. When a square thread screw is to be made, the sharp dies must be removed after the indentation is sufficiently deep to admit the square dies, which are to be substituted for the former; when these have cut the screw to a considerable depth, a smaller set of square dies is taken in succession, until the screw is finished.

N.B. Figs. 15 and 16 represent a small stock made of steel, and hardened, for holding the cutter while sharpening. Figs. 17 and 18 represent an edge and side view of the cutter. Figs. 13 and 14 represent the dies.

ARCHIMEDES'S SCREW, or the *Watersnail*, is a machine for raising water, which consists either of a pipe wound spirally round a cylinder, or of one or more spiral excavations formed by means of spiral projections from an internal cylinder, covered by an external coating, so as to be watertight. This screw is one of the most ancient, and at the same time ingenious, machines we know, being truly worthy of the name it bears, supposing Archimedes to be the real inventor. Though simple in its general manner of operation, its theory is attended with some difficulties which could only be conquered by the modern analysis: it was first stated correctly, as far as we have been able to ascertain, by M. *Pitot*, in the *Mémoires de l' Academie Royale des Sciences*, and afterwards more elaborately by *Euler* in *Nov. Comment. Petropol. tom. 5*. Later attempts by *Langsdorf* in his *Handbuch der Maschinenlehre*, and some other authors, are not to be relied on. That the nature of this curious machine may be the better understood, we shall first state generally its manner of operation; and then present a more particular view of the calculus necessary to show the work it will really perform, and the force required as a first mover.

1. If we conceive that a flexible tube is rolled regularly about a cylinder from one end to another; this tube or canal will be a screw or spiral, of which we suppose the intervals of the spires or threads to be equal. The cylinder being placed with its

axis in a vertical position, if we put in at the upper end of the spiral tube a small ball of heavy matter, which may move freely, it is certain that it will follow all the turnings of the screw from the top to the bottom of the cylinder, descending always as it would have done had it fallen in a right line along the axis of the cylinder, only it would occupy more time in running through the spiral. If the cylinder were placed with its axis horizontally, and we again put the ball into one opening of the canal, it will descend, following the direction of the first demi-spire; but when it arrives at the lowest point in this portion of the tube it will stop. It must be remarked that, though its heaviness has no other tendency than to make it descend in the demi-spire, the oblique position of the tube, with respect to the horizon, is the cause that the ball, by always descending, is always advancing from the extremity of the cylinder whence it commenced its motion, to the other extremity. It is impossible that the ball can ever advance more towards the further, or as we shall call it, the *second* extremity of the cylinder, if the cylinder placed horizontally remains always immovable: but if, when the ball is arrived at the bottom of the first demi-spire, we cause the cylinder to turn on its axis without changing the position of that axis, and in such manner that the lowest point of the demi-spire on which the ball presses becomes elevated, then the ball falls necessarily from this point upon that which succeeds, and which becomes lowest; and since this second point is more advanced towards the second extremity of the cylinder than the former was, therefore by this new descent the ball will be advanced towards that extremity, and so on throughout, in such a manner that it will at length arrive at the second extremity by always descending, the cylinder having its rotatory motion continued. Moreover, the ball, by constantly following its tendency to descend, has advanced through a right line equal to the axis of the cylinder, and this distance is horizontal, because the sides of the cylinder were placed horizontally. But if the cylinder had been placed oblique to the horizon, and we suppose it to be turned on its axis always in the same direction, it is easy to see that if the first quarter of a spire actually descends, the ball will move from the lower end of the spiral tube, and be carried solely by gravity to the lowest point of the first demi-spire, where, as in the preceding case, it will be abandoned by this point as it is elevated by the rotation, and thrown by its heaviness upon that which has taken its place: whence, as this succeeding point is further advanced towards the second extremity of the cylinder, than that which the ball occupied just before, and consequently more elevated; therefore the ball while following its tendency to descend by its heaviness, will be

always more and more elevated by virtue of the rotation of the cylinder. Thus it will, after a certain number of turns, be advanced from one extremity of the tube to the other, or through the whole length of the cylinder; but it will only be raised through the vertical height determined by the obliquity of the position of the cylinder.

Instead of the ball, let us now consider water as entering by the lower extremity of the spiral canal, when immersed in a reservoir: this water descends at first in the canal solely by its gravity; but the cylinder being turned, the water moves on in the canal to occupy the lowest place; and thus by the continual rotation is made to advance further and further in the spiral, till at length it is raised to the upper extremity of the canal where it is expelled. There is, however, an essential difference between the water and the ball: for the water, by reason of its fluidity, after having descended by its heaviness to the lowest point of the demi-spire, rises up on the contrary side to the original level; on which account more than half one of the spires may soon be filled with the fluid. This is an important particular, which, though it need not be regarded in a popular illustration, must be attended to in the more particular exhibition of the theory to which we now proceed.

2. The most simple method of tracing a screw or a helix upon a cylinder is well known to be this: take the height or length of a cylinder for one leg of a right-angled triangle, and make the other leg equal to as many times the circumference of the base of the cylinder, as the screw is to make convolutions about the cylinder itself; then if this triangle be enveloped about the surface of the solid, the two legs being made, the one to lie parallel to the axis of the cylinder, the other to fold upon the circumference of its base, the hypothenuse will form the contour of the screw. Suppose therefore here, that upon the cylinder ABCD (fig. 6. pl. XXIV.) we have rolled the right-angled triangle BDE, and that its hypothenuse DE traces upon the cylinder the contour of the helix or the spires BF, GH, &c. Then if a tube be formed according to the direction of this spiral, and a small ball put into it, if the cylinder were placed upright, the ball would roll to the bottom with the same velocity and the same force, as it would have descended upon the plane DE, if BE were horizontal and BD vertical. But if the cylinder be inclined until it makes with the vertical CL an angle ACL equal to the angle BED, or the angle which the threads of the screw make constantly with the base of the cylinder, in that case DE will be parallel to the horizon; and whether the spires be few or many, they will all be parallel to the horizon: so that there being nothing to occasion the ball P to move toward either

G or H, it will remain immoveable, supposing the cylinder to be at rest: but if the cylinder be turned on its axis in one direction, the ball (abstracting from friction) will move the contrary way, in conformity with the first law of motion.

3. The inclination ACL = BED which we have just assigned is the least we can give, so that the ball shall not descend of itself: but if we augment this inclination, or make the angle LAC smaller, then by turning the cylinder in the direction CMD, the ball will always have a descent on the side towards H, and will mount, so to speak, by descending. The reason is very simple: *the plane which carries it makes it rise more in consequence of the rotatory motion, than it descends by virtue of the force of gravity.*

4. There are several methods of determining the ratio of the weight of the ball P to the force F, necessary to make it rise by turning the screw. The following is perhaps the most simple: the force or power is to the weight elevated, as the vertical space passed over by the weight, is to the space passed through by the power in moving it. Here the vertical space is CL, and if the moving force act at the circumference of the cylinder, the space passed over by that force will be equal to as many times the circumference of the cylinder's base, as there are convolutions of the helix: thus we shall have BE : CL :: P : F.

Example. Let the diameter AB of the cylinder be 14 inches, the vertical altitude CL = 12 feet or 144 inches, and 12 the convolutions of the spiral, the cylinder being so placed that the angle LAC is less than BED; the weight to be raised being a 48lb. ball. Then the circumference of the cylinder will be nearly 44 inches, and the 12 turns equal to $12 \times 44 = 528 =$ BE. Hence we have 528 : 144 : : P : F : : 48 : $13\frac{1}{3}$lbs. the measure of the requisite force at the surface of the cylinder. If the moving force describe a circle whose diameter is 3 times that of the cylinder, or act at a winch, whose distance from the axis of motion is 21 inches, that force will then be reduced to $\frac{1}{3}$ of $13\frac{1}{3}$ or $4\frac{4}{9}$lbs. which is less than $\frac{1}{10}$ of the weight of the ball. The friction upon the pivots, &c. is not here considered.

Thus it appears that Archimedes's screw may be used for other purposes than raising of water. It might be adapted with advantage in raising cannon balls from a ship to a wharf; and with the addition of a bevel-wheel or two and their pinions, might be worked by either men or horses.

5. The helix formed about a cylinder is a curve similar in all its parts: that is, all the demi-spires, as AIC, CR, RS, are similar and equal; is is also the same of the thirds, the fourths, &c. of the spires, and generally of all the equal portions of the curve.

But when the cylinder is inclined, if we refer all the points of a demi-spire, such as AIC, by perpendiculars, to the horizontal section of the cylinder (which section is elliptical, though represented in fig. 7. pl. XXIV. by a right line AD to prevent confusion in the diagram), we shall find that this demi-spire has, with regard to the horizontal plane AD, a highest point E, a lowest point E′, and a mean point I. In order to become acquainted with the effect of the screw in raising water, it is important to determine these three points.

6. The mean point I is a point of inflection very easy to determine. To this end put the diameter $AB = 2r$, the half-circumference $AMB = c$, the abscissa $AP = x$, the indeterminate arc $AM = s$, the ordinate ME of the spiral $= y$, and the height BC of a demi-spire $= h$. Hence, since we may consider the demi-spire AIC as having been formed by the hypothenuse of a right-angled triangle, one leg of which is equal to the half-circumference AMB, and the other equal to the line BC, we have this proportion, AMB : BC : : AM : ME, or $c : h :: s : y$; whence, $s = \frac{cy}{h}$, the fluxion of which is $\dot{s} = \frac{c\dot{y}}{h}$. But by the nature of the circle $\dot{s} = \frac{r\dot{x}}{\sqrt{(2rx - x^2)}}$; so that $\frac{r\dot{x}}{\sqrt{(2rx-x^2)}} = \frac{c\dot{y}}{h}$. Therefore, following the usual method for points of inflexion, by taking the second fluxions and supposing $\dot{x}$ constant, we have $\frac{hr\dot{x}x^2 - hr^2\dot{x}^2}{c\sqrt{(2rx-x^2)}} = \ddot{y} = 0$, which gives $x = r$, and indicates that the point of inflexion I is in the middle of the demi-spire AIC.

7. To find the highest and lowest points E, E′, in addition to the characters before used, put $BD = a$, and $AD = f$: we have from the foregoing article $\frac{hs}{c} = y$, and the similar triangles ABD, APF, give AB : BD : : AP : PF, or $2r : a :: x : \frac{ax}{2r} = PF$. Therefore $EF = PE - PF = \frac{hs}{c} - \frac{ax}{2r}$; for since we consider PM as perpendicular to PE, it follows that ME and PE will be equal, and consequently $PE = \frac{hs}{c}$. The similar triangles ABD, EFG, give AD : AB : : EF : EG, or, $f : 2r :: \frac{hs}{c} - \frac{ax}{2r} : \frac{2hrs}{cf} - \frac{ax}{f} = EG$. This value of EG ought to be a *maximum;* its fluxion, therefore, that is, $\frac{2hr\dot{s}}{cf} - \frac{a\dot{x}}{f} = 0$. But from the nature of the circle we have $\dot{s} = \frac{r\dot{x}}{\sqrt{(2rx-x^2)}}$. Substituting for $\dot{s}$ in the preceding equation this value of it, and reducing, we soon find $x =$

$r \pm \frac{r}{ac} \sqrt{(a^2c^2 - 4h^2r^2)}$. Of these two values of x, the lower determines the value AP corresponding to the highest point E; the upper shows the value AP$'$ corresponding to the lowest point E$'$.

8. Through the highest point E having drawn the horizontal plane EO, this plane will cut the demi-spire COS in the point O (fig. 8. pl. XXIV.), thus determining the arc ECO which carries water, or as it is sometimes called the *hydrophorous arc*; for all the points of this arc being below the points E, O, and these two points being in the level of the surface, the water will be in equilibrio in that arc. To find the magnitude, and of consequence the quantity of water carried by an hydrophorous arc, the diameter of the tube which forms the screw being given, it is evident that we have only now to determine the point O or extremity of the arc ECO, the other extremity having been found by the preceding article. In order to this, denote AB, BD, by the same letters as before; the variable abscissa BQ by z, and its arc BN by s: the line EF (found as in art. 7.), or its equal OR put $= e$. Then the similar triangles ABD, AQR, give AB : BD : : AQ : QR, or $2r : a : : 2r - z : \frac{2ar - az}{2r} =$ QR: therefore QO $= \frac{2ar - az}{2r} + e$. Now, by the property of the screw, we have AMB : BC : : AMBN : NO, or $c : h : : c + s : \frac{hc + hs}{c} =$ NO. But QO and NO being two lines perpendicular to the base of the cylinder, and both of them terminating in the plane of the ellipse, or of the cylindric section EO, it follows that QO = NO; that is, from what has gone before, $\frac{2ar - az}{2r} + e = \frac{hc + hs}{c}$, or $\frac{az}{2r} + \frac{hs}{c} + h - a - e = 0$. As the resolution of this equation depends upon the rectification of the arc s, we can only substitute the value of s in terms of z, by an infinite series formed of z and its powers; where the resulting equation becoming more and more complex and embarrassing, as a greater number of terms of the series is taken, we should, by pursuing it, be involved in a very long and tiresome operation: to avoid this we shall have recourse to the following table calculated by M. Pitot.

This table contains values of the arcs BN $= s$, corresponding to those of BQ $= z$, given in parts of the diameter AB $= 2r$, divided into 200 parts. This granted, having found by the preceding article the value of e, we reduce $h - a - e$ to one number only, which let be represented by n: then have we $\frac{az}{2r} + \frac{hs}{c} = n$. Lastly, we take in the table different values of z and of the

corresponding arc, till we have discovered that which renders $\frac{az}{2r} + \frac{hs}{c}$ equal to the number n, or nearly so.

To find the length of the hydrophorous arc ECO, having determined the arcs AM and BN, it is proper to observe that, by the formation of the screw (art. 2.), the length of one of the demi-spires AEC is equal to the hypothenuse of a right-angled triangle, of which AMB $= c$, and BC $= h$ are the legs: thus the demi-spire AEC $= \sqrt{(cc + hh)}$. If now we put m for the known arc MBN, we may take this analogy, viz. AMB : AEC : : MBN : ECO, or $c : \sqrt{(c^2 + h^2)} : : m : \frac{m}{c} \sqrt{(c^2 + h^2)} =$ ECO, and thus obtain the value of the arc which carries the water, or of the hydrophorus arc sought.

Table of arcs corresponding to parts of radius divided into 100 *equal parts.*

Part of radius.	Arcs in parts of radius.	Arcs in deg. and min.	Parts of radius.	Arcs in parts of radius.	Arcs in deg. and min.
1	14·14	8° 6′	18	60·88	34°54′
2	20·	11 28	19	62·62	35 54
3	24·54	14 4	20	64·31	36 52
4	28·35	16 15	21	65·94	37 48
5	31·72	18 11	22	67·57	38 44
6	34·77	19 56	23	69·17	39 39
7	37·59	21 33	24	70·74	40 33
8	40·24	23 4	25	72·73	41 25
9	42·71	24 29	26	73·73	42 16
10	45·06	25 50	27	75·21	43 7
11	47·30	27 7	28	76·66	43 57
12	49·45	28 21	29	78·16	44 46
13	51·52	29 32	30	79·52	45 35
14	53·52	30 41	31	80·90	46 22
15	55·44	31 47	32	82·25	47 9
16	57·30	32 51	33	83·62	47 56
17	59·16	33 55			

9. *Example of the calculation of an hydrophorous arc.* For an example of this kind of calculation for the length of the hydrophorous arc ECO, let us take the diameter AB $= 2r$ of 200 parts, the height BC $= h = 80$ of the same parts, BD $= a = 100$ parts; then the semi-circumference AMB will be nearly $= 314$ of those parts. Substituting these values in the expression $x =$

$r - \frac{r}{ac}\sqrt{(a^2c^2 - 4h^2r^2)}$ (art. 7.), there results AP $= x = 13{\cdot}45$ of the same parts: and by means of the table just given, the arc AM $= s$, is found $= 53{\cdot}3$. Substituting these values of x and s in the equation $\frac{hs}{c} - \frac{ax}{2r} = e$, we find the value, e, of EF or RO $= 6{\cdot}86$.

To have at the same time the value of BQ $= z$, and of the arc BN which we now call s; these values of a, h, c, $2r$ and e must be substituted in the equation $\frac{az}{2r} + \frac{hs}{c} = a - h + e$, so as to have $z + \frac{805}{157} = 53{\cdot}72$. By means of the preceding table it is soon found that BQ $= z = 21$, and BN $= s = 66$, very nearly.

Then to find the arc MBN, which we have called m, we have the whole arc AMBN $= 314 + 66 = 380$, from which deducting the arc AM $= 53{\cdot}3$, there remains MBN $= m = 326{\cdot}7$. The length of the demi-spire AEC $= \sqrt{(c^2 + h^2)} = 324{\cdot}03$: and finally $\frac{m}{c}\sqrt{(c^2 + h^2)} = 337{\cdot}13$ the length of the hydrophorus arc ECO.

10. *The diameter of the cylinder of the screw being given with that of the tube which forms the spiral, and the given length of the screw, to find the quantity of water carried by the hydrophorous arcs, and the height to which the water is elevated the inclination of the spiral being as before.*

Let the diameter AB of the screw be 1 foot, that of the spiral tube in which the water is raised 3 inches, and the length of the screw 30 feet. This granted, to have the length in feet and inches of an hydrophorous arc, say, as the 200 parts of the diameter of the table: 1 foot or 12 inches : : 337·13 before found : 20·2278 inches, the real length of the hydrophorous arc. Every such arc then carries a cylinder of water 3 inches diameter and 20·2278 inches long. Let us next inquire how many such arcs there will be in the whole length of the screw, or 30 feet. It is evident, in the first place, that every turn or convolution of the helix on the arbor of the screw carries one hydrophorous arc: to find, therefore, the number of turns, it must be observed that the height BC of one of the demi-spires is in our example 80 parts, or the height AS of an entire spire 160 parts; the diameter AB of the base, which is 1 foot, being 200 of those parts: hence 200 : 12 : : 160 : 9·6 inches, the height of one spire. Dividing the inches in 30 feet by 9·6, the quotient gives more than 37 for the number of spires; consequently there will be 37 hydrophorous arcs. The quantity of water in all these

hydrophorous arcs is equal to the quantity in a cylinder the diameter of whose base is 3 inches, and height $= 20\cdot2278 \times 37 = 748\cdot4286$ inches, or nearly $62\frac{1}{3}$ feet. Such a cylinder of water is easily found to weigh 191·313 lbs. avoirdupois.

We have now to determine the vertical height to which the screw we have taken for an example will elevate the water: and this may be accomplished very easily; for, the triangles ADB, BYZ, being similar, we have AD : AB : : BY : YZ = 26·833 feet. Finally, under this head, to find the angle which the arbor or axle of this screw makes with the horizon, say, as BD : BA : : rad. : tan. ADB = tan. YBZ the angle sought: thus the angle YBZ is found $= 63° 26'$.

11. *Computation of the force requisite to turn the screw.*— In the example we have taken, the weight of the water contained in the 37 hydrophorous arcs being 191·313 lbs. to find the force necessary to be applied at the circumference of the cylinder, we must say, according to the rule in art. 4. as 37 times the circumference of the cylinder's base (= 1395·714 inches) is to the vertical height through which the water is elevated (= 26 f. 10 i. = 322 inches), so is the weight of water (=191·313 lbs.) to the weight 44·14 lbs. equivalent to the force which must be applied to the circumference of the screw to keep it in motion when once it has begun to turn. But if this force or power, instead of being applied at the circumference of the screw, acts by a handle and winch at the distance of 10 inches from the axis of the cylinder, the requisite force will only be $\frac{6}{10}$ or $\frac{3}{5}$ of the former; it will, therefore, be 26·48 lbs.

12. *Computation of the quantity of water which the screw will raise in a given time.*—To find the quantity of water raised by the screw proposed as our example, we must know the velocity with which the assigned force carries round the handle. Suppose, for instance, the handle, and consequently the screw, makes one rotation in 5 seconds, it is very manifest the screw will then expel the quantity of water contained in 1 hydrophorous arc in 5 seconds; and in 37 times 5 seconds, that is 185 seconds or $3^m\ 5^s$, it will raise a quantity weighing 191·313lbs. To find the quantity raised in an hour, say, as 185 : 3600 (seconds in an hour) : : 191·313 : 3719lbs. nearly. Or, if the quantity be calculated in ale gallons, it will be found equal to 364·62. If the velocity with which the handle is moved be tripled, which it may be without rendering the work too fatiguing, the quantity raised will be tripled, and nearly 1094 gallons will be raised 26 feet 10 inches in an hour. This coincides very nearly with Desaguliers's estimate of the water which a man can raise by almost any hydraulic engine.

13. Having dwelt thus long upon the theory of Archimedes's screw, but little remains to complete our observations. It is obvious from what has been remarked, that this screw can never raise water when the angle which the central line of the spiral makes with the base of the cylinder is larger than the angle included between the base of the cylinder and the horizon; that is, it is always necessary that BAZ should be equal to, if not greater than, BED (fig. 6. pl. XXIV.) In practice, indeed, it is advisable that CAL be between 40° and 60°, and BAZ – BED between 10° and 20°. The mean of both these is most to be recommended.

Sometimes Archimedes's screw, instead of being worked by men at a winch, is turned by means of float-boards fixed about the circumference of its lower end, upon which a stream of water acts: if the water have a moderate fall, it will have sufficient efficacy to turn two screws, one above another; the top of the lower screw and the bottom of the upper screw may act the one upon the other, by means of a wheel upon each with an equal number of teeth taking into each other: in this case the upper screw will turn in a contrary direction from the other, and consequently the spiral tube must be wound about the cylinder in an opposite direction. A solid wheel, or a light wheel with a heavy rim, turning upon the middle of the screw as an axis, will operate like a fly, and in some cases be very useful.

In the preceding investigations no notice has been taken of the effects of the air included in the spiral: yet if the spiral had been folded upon a cone instead of a cylinder, or if it had been formed of a flexible tube of varying diameter, these effects would have been important: some of them are considered in our account of the spiral pump. See HYDRAULIC *Machines*, No. 10.

M. Cagniard, formerly an élève of the Polytechnic School, has struck out a very ingenious application of Archimedes's screw. He employs it as bellows, in a machine which produces rotatory motion by means of a reservoir of hot water. When the screw is turned in the direction of the motion of the points which described the helices of which its threads are composed, the water which bathes the lower extremity of the screw does not rise in its threads, but still farther descends below the screw, being replaced by the exterior air which escapes through the orifices of these threads. Thus M. Cagniard causes the air to descend to the bottom of a vessel full of water of the temperature of the atmosphere: another vessel filled with water to 180° or 200° (of Fahrenheit) contains a cylinder which is moveable on its axis, and is entirely immersed in the water: this

cylinder is furnished with spouts in the direction of its length. The cold air passes from the bottom of the first vessel to that of the second, by means of a syphon; it enters the spouts of the cylinder, there becomes heated, and forces the cylinder to turn. The rotatory motion of the axis of the cylinder is transmitted to the axis of the Archimedean screw, and the motion of the cylinder is continued solely by the action of the hot water upon the atmospheric air.

For various purposes to which this improvement may be applied, see Hachette, *Traité de Machines*, p. 149—154.

SHIP *Block Machinery*. See BLOCK.

SHOEMAKERS' IMPLEMENT, *to enable them to work in a standing posture*. Such an instrument has been contrived by Mr. Thomas Holden of Fettleworth, Sussex; and its inventor rewarded with fifteen guineas by the Society of Arts. It resembles a stand, such as is used for reading desks; at the top of which is a small block of wood, excavated so as to form a proper bed for the last, and the moulds or instruments used in making boots, which are kept firm upon it, by a stirrup or endless strap. The hollow block is joined into another piece (which connects it to the stand), so as to admit of a vertical motion; and it is retained, at any angle, in this motion, by a circular catch, with notches formed in its side, to fasten it on an iron catch projecting from the lower piece. This lower piece is shaped into a small cylinder beneath, which entering into a hole formed for it on the top of the pillar of the stand, permits the hollow block to be moved round about, without stirring the stand; so that, by the combination of these two motions, it may be placed in any position. Behind the hollow block, and on a level with it, an horizontal piece of board is supported by a small pillar, rising from one of the feet of the stand, and secured firmly by a brace to the stand itself: this board supports the tools and implements wanted, ready at hand for the workman's use.

The design of this invention is to obviate the necessity of using that very unwholesome posture in which shoemakers are accustomed to work; which compresses the lungs and bowels in such a manner, as to occasion consumption, inflammation of the bowels, and a variety of other frightful complaints.

The efficacy of the alteration of posture permitted by this instrument, which enables the workman to stand at his work, is very well proved in the case of the inventor of it; who has produced a medical certificate, that he was for many years so afflicted with bowel complaints and piles, that he was under the necessity of leaving off his trade entirely, if he could not contrive to work standing; and that, since he has made use of this im-

plement, his complaints are entirely removed, and he is so improved in flesh and countenance, that he "looks not like the same man;" and, for some years, has had no occasion for medicine. He has made many hundred pairs of shoes on this stand, and recommends also its use, "as the quickest way of closing all the thread work."

This implement might be made still more simple, by leaving out the part used to give the hollow block a circular motion, which does not appear always necessary, from the facility which the workman has, when standing at it, to place himself instantly at any side of the work he pleases; it would, as appears to us, be full as little, if not less, trouble to him to let the instrument remain unmoved, and turn himself round instead of it, as to stand still while he turned it about: though a small quantity of light confined to one direction may in some cases render the increased apparatus necessary.

A wooden vice of a proper height, fixed to a stake, and secured even by a wedge, if a screw should be deemed expensive, would also hold a last in any position required for the workman.

Another contrivance for this purpose by Mr. J. King, has been lately recommended by the same society. The machine consists of an oblong frame of wood of two sides, with cross pieces. It may be conveniently fixed in a situation, and at a proper height for working, by screwing down to a window-sill, by means of two screws, such as are used for bedsteads. These and an iron bracket, extending from the front of the machine, being screwed against the wainscot, support the machine very steadily; or a stand, consisting of proper legs, may be used, if preferred. The external parts of the machine are covered with leather, so as to become like cushions to support the last, and it is held down by a strap, which has a loop or treadle at the bottom, for the foot. The principal novelty of this invention consists in a lever, which is attached by an iron link to a wire, upon which it moves as a centre; and when that is down in its place, a small point or beak of iron enters into holes made in an iron plate; and the other end of the lever comes to rest on a stop, which has several holes in it. The end of the lever has, also, a little iron beak, which enters these holes. Thus, when the lever is down, it becomes an immoveable cross-bar of the frame, and the last may be held or wedged in between this, and either slide of the frame, and held down by the strap. But to adjust the width of the opening, on which the last lies, nothing more is necessary than to lift up the lever, so that the point clears the holes of the plate, then sliding the link along the wire, to the intended width, and shutting it down again, the

beak or point enters some other hole of the plate, and holds the lever fast in the new position, so as to adapt it to the width of any last, or to hold it in any position, at pleasure.

Mr. King observes that, at other times, the last is held down by the foot-strap pressing the lever upon it—that the machine forms an universal vice, supporting and holding the last firmly down upon the cross-bar, in any required position. Two stiff pieces of sole-leather are also fixed in the frame, which, in certain positions, support the last.

SIPHON. See CRANE.

SPIRAL-PUMP, *at Zurich.* See HYDRAULIC *Engines*, No. 10.

STEAM-ENGINE, an engine originally contrived for raising water by means of the expansive force of the steam or vapour produced from water or other liquids in a state of ebullition. This has been often called the *Fire-engine*, because of the fire used in boiling the liquid; but the latter term has, of late, been properly confined to machines for extinguishing fires. The steam-engine is justly deemed one of the most curious, important, and serviceable mechanical inventions, not only of modern, but of any times; particularly when it is considered with regard to some of its late improvements, which render it applicable to all kinds of mill-work, to planing, sawing, boring, and rolling machines, and indeed to almost every purpose that requires a powerful first mover, whose energy may be modified at the pleasure of the mechanist.

The principles and manner of operation of the steam-engines of Savery, Newcomen and Cawley, and of Watt, may be understood from the following brief explanations and remarks, which are meant as preparatory to the more detailed accounts of several engines with which we have been favoured.

1. Let there be a sucking pipe with a valve opening upwards at the top, communicating with a close vessel of water, not more than thirty-three feet above the level of the reservoir, and the steam of boiling water be thrown on the surface of the water in the vessel, it will force it to a height as much greater than thirty-three feet as the elastic force of the steam is greater than that of air; and if the steam be condensed by the injection of cold water, and a vacuum thus formed, the vessel will be filled from the reservoir by the pressure of the atmosphere; and the steam being admitted as before, this water will also be forced up; and so on successively.

Such is the principle of the first steam-engine, said by the English to be invented by the *Marquis of Worcester;* while the French ascribe it to *Papin:* though we believe the fact is that *Brancas*, an Italian, applied the force of steam ejected from a

large eolipile as an impelling power for a stamping-engine so early as 1629. The hint so obscurely exhibited in the Marquis of Worcester's Century of Inventions (see the word WORCESTER in this alphabetical arrangement) was carried into effect by Captain Savery.

2. If the steam be admitted into the bottom of a hollow cylinder, to which a solid piston is adapted, the piston will be forced upwards by the difference between the elastic forces of steam and common air; and the steam being then condensed, the piston will descend by the pressure of the atmosphere, and so on successively. This is the principle of the steam-engine first contrived by Messieurs *Newcomen* and *Cawley*, of Dartmouth. This is sometimes called the atmospherical engine, and is commonly a forcing-pump, having its rod fixed to one end of a lever, which is worked by the weight of the atmosphere upon a piston at the other end, a temporary vacuum being made below it by suddenly condensing the steam, that had been admitted into the cylinder in which this piston works, by a jet of cold water thrown into it. A partial vacuum being thus made, the weight of the atmosphere presses down the piston, and raises the other end of the straight lever, together with the water, from the well. Then immediately a hole is uncovered in the bottom of the cylinder, by which a fresh quantity of hot steam rushes in from a boiler of water below it, which proving a counterbalance for the atmosphere above the piston, the weight of the pump rods, at the other end of the lever, carries that end down, and raises the piston of the steam-cylinder. The steam hole is then immediately shut, and a cock opened for injecting the cold water into the cylinder of steam, which condenses it to water again, and thus making a vacuum below the piston, the atmosphere again presses it down and raises the pump-rods, as before; and so on continually.

3. The great features of improvement made by Mr. *Watt* upon the engine of Newcomen and Cawley are, as Mr. Nicholson remarks, first, that the elasticity of the steam itself is used as the active power in this engine; and, secondly, that besides various other judicious arrangements for the economy of heat, he condenses the steam, not in the cylinder, but in a separate vessel.

In the cylinder or syringe, concerning which we have spoken, in mentioning the engine of Newcomen, let us suppose the upper part to be closed, and the piston-rod to slide air-tight through a collar of leathers. In this situation, it is evident that the piston might be depressed by throwing the steam upon its upper surface, through an aperture at the superior end of the cylinder.

But if we suppose the external air to have access to the lower surface of the piston, we shall find that steam no stronger in its elasticity than to equal the weight of the atmosphere would not move the piston at all; and consequently, that this new engine would require much denser steam, and consume much more fuel, than the old engine. The remedy for this evil is to maintain a constant vacuum beneath the piston. If such a vacuum were originally produced by steam, it is certain that its permanency could not be depended on, unless the engine contained a provision for constantly keeping it up. Mr. Watt's contrivance in his simplest engine is as follows; The steam is conveyed from the boiler to the upper part of the cylinder through a pipe, which also communicates occasionally with the lower part, and beyond that space with a vessel immersed in a trough of water; in which vessel the condensation is performed by an injected stream of cold water. This water is drawn off, not by an eduction-pipe, but by a pump, of which the stroke is sufficiently capacious to leave room for the elastic fluid, separated during the injection, to follow and be carried out with the injection water. Suppose now the piston to be at its greatest elevation, and the communication from the boiler to the upper as well as to the lower parts of the cylinder to be opened. The steam will then pass into the whole internal part of the engine, and will drive the air downwards into the condenser, and thence through the valves of the air-pump. In this situation, if the communication from the boiler to the lower part of the cylinder be stopped, and an injection be made into the condenser, a vacuum will be produced in that vessel, and the steam contained in the lower part of the cylinder and communication pipe will expand itself with wonderful rapidity towards the condenser, so that, in a period of time too minute to be appreciated, the whole of the steam beneath the piston will be practically condensed. The steam which continues to act above the piston will immediately depress it into the vacuum beneath: at the same time that by connexion with the external apparatus the piston of the air-pump also descends in its barrel. When the stroke is nearly completed downwards, the requisite part of the apparatus shuts the communication with the boiler, opens that between the upper and lower parts of the cylinder and condensing vessel, and turns the injection cock. At this very instant the piston loses its tendency to descend, because the steam presses equally on both surfaces, and continues its equality of pressure while the condensation is performed. It therefore rises; the injection is stopped; and the air-pump making its stroke, suffers the injection water and a considerable part of the elastic fluid to pass through its lower

valve. The vacuum is thus kept up through the whole internal capacity of the engine. As soon as the piston has reached the upper part of the cylinder, the communication to the under part of the cylinder is stopped, and that with the boiler opened, as before; the consequence of which is, that the piston again descends; and in this manner the alternations repeatedly take place.

The principal augmentation of power in this engine, compared with that of Newcomen, arises from the cylinder not being cooled by the injection water, from its being practicable to use steam, which is more powerful than the pressure of the atmosphere, and from the employing of this steam both to elevate and to depress the piston. In general, these engines are worked by steam, which would support a column of four or five inches of mercury besides the pressure of the atmosphere, and sometimes more; for Mr. Nicholson says, he has sometimes seen the gage as high as eight inches. Mr. Watt has made several successive modifications and additions to the engine just described, some of which will be further spoken of in the course of this article.

In the first edition of this work there was inserted a history of the successive improvements in the steam-engines by Mr. *J. C. Hornblower**; instead of which I shall now insert an abridgment of that history, and of the Edinburgh Reviewer's reply to it, as given in the fifth volume of the "Retrospect of Philosophical and Mechanical Discoveries," &c.

4. *Mr. Hornblower's account of the Steam-engine.*—After remarking that it is unnecessary to dwell upon the early part of this history, already treated by Desaguliers and his followers, Mr. Hornblower observes, there are, however, some particulars during this period which deserve notice. One of these relates

* As I have been exposed to much calumny and misrepresentation for admitting that historic sketch into my work, I beg to remark that I did it *solely* from motives of benevolence. Till the time my second volume was preparing for the press, I knew nothing of Mr. Hornblower: but a friend of mine, on whose judgment I placed great reliance, who was well acquainted with Mr. H. and thought highly of his moral character, as well as of his mechanical skill, had a full persuasion that through a series of unfortunate circumstances, he had never had justice done him, and urged me to allow Mr. Hornblower to tell his own story. I yielded to his solicitations; and in consequence exposed myself to the malevolence of certain writers, who in one short note of ten lines (*Edin. Rev.* vol. xiii. p. 327), published *four* positive, wilful falsehoods, for the honourable purpose of injuring my reputation. I however forgive them, although they treated me unjustly; and trust they will ere now have forgiven me, for permitting an injured (though perhaps hasty) man to defend his own cause, and that of his family. He is now beyond the reach of those who wished to promote his welfare, as well as of those who, by unfairly depreciating his character, involved him in ruin. His latter years were rendered comfortable, not by the liberality of his own countrymen, but of an opulent and scientific *Swede*, who knew how to appreciate and to reward his merit as an engineer.

to Desaguliers's account of the method of leathering the piston, in which Mr. H. thinks he has erred in stating it to have been discovered by accident. Another respects what he says of an experiment made by Mr. Beighton, with a view of ascertaining the comparative magnitude of such steam as was generally used for working an engine, in respect to the quantity of water from which it was produced, and which is stated to be in the ratio of 13,338 to 1; but which Mr. H. from Mr. Beighton's statement, calculates at 2,655$\frac{1}{2}$ to 1; and he considers even this to be more than what may be observed in some of the most improved engines of the present time. He also conceives that experiments of this nature and date have either been conducted or related in so loose and inaccurate a manner, that little dependence can be placed upon the results.

Friction and inertia were at this time considered as the two grand objects which the engineer had to overcome; and some different modes of condensation were tried, but without much advantage being derived from them. The water in the piston, whenever it was a tight one, became hot, and a considerable degree of heat was expended in its evaporation. Several improvements, however, were attempted in the construction of boilers, some of which succeeded, and are still in use: but the grand obstacle was to be surmounted by Mr. Watt. Previous to Mr. Watt's improvements, the boring of the cylinders had been executed in a very imperfect manner; and in several of those engines in which the water obtained from the mines was used for condensing the steam, this defect soon became so much increased by its corroding properties, that it was almost impossible to keep the piston tight, and in some cases the packing was rammed so hard as to sustain the whole pressure of the atmosphere.

Such was the general state of this engine when Mr. Watt obtained his patent in 1769, and engaged to grant licenses for the use of his improved engines, on the condition of receiving one-third of the advantage which should result from the saving of fuel in working those of his construction. Much of the merit ascribed to Mr. Watt, for the improvement in boring the cylinders, Mr. H. says is really due to Mr. Wilkinson, with whom it, as well as most of what related to the iron-foundery, originated. The method of condensing the steam in a separate vessel, is likewise said to have been discovered by a Mr. Gainsborough, about the time that Mr. Watt was engaged in bringing forward his improvements, and communicated to Mr. Watt by an officious acquaintance of Mr. Gainsborough.

An attempt had been made before this time to drain some of the deep mines of Cornwall, by a new application of Savery's

engine, furnished with an apparatus for opening and shutting the usual communications by means of cocks and valves. In this application it was proposed to employ the force of steam expansively, with a stratum of air between it and the water, to prevent its condensation; and Mr. Blakey obtained a patent for his improvements: but one of the steam-vessels bursting before the steam had attained a sufficient power for the intended purpose, showed the impracticability of the scheme, and it was abandoned.

Mr. Hornblower thinks that those who have attempted to estimate the defects of Newcomen's engine have erred in stating the vacuum to be such only as would cause a weight to be raised of about 7½ pounds for every square inch of the piston; and says that the column of water alone was equal to that weight, independent of both friction and inertia, which were very considerable; he also adds, that he tried the vacuum of several engines in Cornwall, and found that which was least to bear a load of 11·6 pounds on the square inch. Another error has been committed with regard to the purport of the counter-weight attached to the outer end of the lever, which has been stated to be employed to overcome part of the pressure of the atmosphere at the return of the stroke of the engine: "*that is not the case.*" It is used for the purpose of regulating the speed of the engine's working, and both the weight and the end of the lever on which it is placed are to be varied by the attendant according to circumstances; the three principal of these that require to be attended to in this regulation, are, "first, that the pump-buckets shall descend, but without such force as may endanger the breaking of the pump-rods; secondly, that this descent shall nevertheless be as quick as possible: but, thirdly, that it shall not impede the discharging functions of the engine." With respect to the application of steam, the old atmospheric engine possesses one advantage which Mr. Watt's single engine does not admit. In pumping water from mines, it is necessary that the speed of the engine should be regulated according to the influx of the water; and in the old engine this is effected by merely regulating the intensity of the fire, as by this means the force of the steam on the lower side of the piston may be varied from an equilibrium with the pressure of the atmosphere to exceed it by two pounds on each square inch of the piston, which, in a cylinder of 60 inches in diameter, amounts to a force of 7200 pounds. This advantage, however, relates only to the working of pumps; for since its application to the purposes of giving motion to mill-work, it has been a desideratum to maintain a uniform force or action on the crank, in order to produce the same effect on the fly. When the engine

was first applied for the purpose of producing rotative motion, it had not the advantage of a double stroke, as at present; and the mode of equalizing the strokes was by a rod which connected the engine and the mill together, or a weight laid on that end of the lever. This mode, when applied to the old engine, required that the work to be performed by it was nearly of an uniform nature during the time of its action. But Mr. Watt accommodated this circumstance in his single engine by rendering the discharge constant, and not liable to be affected by any variation in the resistance, and checking the entrance of steam by a contrivance that prevents the plenum valve from opening to its greatest extent. The first notice, however, of a rotative motion being communicated by the steam-engine, was about the year 1778, when Mr. Washbrough obtained a patent for that principle, and applied it at his own works for turning lathes and other purposes.

The valve by which the air is discharged, and called the blowing valve, Mr. H. says, was not applied to any of Mr. Watt's engines previous to his going into Cornwall, as before that time this operation was usually performed by a temporary brake attached to the discharging pump. This valve was first applied by Mr. Hornblower at an engine on a mine called Ting Tong, which he erected for the *proprietors*, and not for Messrs. Boulton and Watt, as has been stated.

The most novel circumstance in the operation of Mr. Watt's single engine, and which is a fine accompaniment of the improver's principal object, is, that when the steam has acted on the piston to the limits of the stroke, it is permitted to re-enter the cylinder below the piston. "It generally happens in engines erected for pumping water, that they are calculated to go deeper than the present bottom of the mine; and therefore, if all the steam which enters the cylinder for one stroke was to be condensed, the engine would act with its whole power, and the effect would be to destroy itself: on which account, in engines thus circumstanced, the injection is to be stopped long before the termination of the stroke which leaves a residuum of steam at the bottom of the cylinder, that proves an effectual banking to the piston; even so far as to support it when the chains to which it is appended have become quite slack by the momentum given to the lever during the action of the steam on the piston. We believe it was this circumstance that indicated to Mr. Watt the advantage of shutting off the steam from the boiler soon after the commencement of the stroke."

As the valve which must be opened at each succeeding stroke of the engine, in order to secure its action, is kept down by a weight equal to the pressure of the atmosphere, added to the

elasticity of the steam above that pressure; and it is necessary that this valve should be opened as quickly as possible; in large engines it requires a considerable force to effect it in such a manner as not to impede the performance of the engine. Mr. Hornblower says that it was suggested to Mr. Watt to make the valves double, by placing a small one in the middle of the larger, and it was adopted; but the difficulty of keeping them in complete repair caused the method to be given up. In all the best engines, a weight or spring was applied for the purpose of opening this valve. But Mr. Jos. Hornblower is said to have constructed this valve on a new principle, in order to effect this purpose more completely; and his mode is here preferred to any that had been previously in use.

Such was the state of Mr. Watt's improvements, and of his single engine, when new wants gave rise to new inventions. Some of the Cornish miners wished to carry their works to a greater depth than could be conveniently done by the engines then in common use, and Mr. Watt invented his double-stroke engine. In the single engine, the piston is connected to the lever by chains lying on the arch of the inner end, but in this it must be connected by a mode that will render the rod rigid in its action upward; and this Mr. Watt has effected by a most ingenious system of transverse joints, which compels the rod to a motion parallel to itself. At the other end of the lever a rod connects the motion of the engine to a fly, by the application of one wheel fixed on the axis of the fly, and another on the rod that is connected to the lever. But, as simplicity is always a desideratum in the construction of machinery, Mr. Hornblower gives the preference to a simple crank with a fly of such weight as may have the required momentum with a less velocity.

A patent was taken out in 1781, for an improvement on Mr. Watt's single engine by Mr. Jonathan Hornblower of Penrhyn. This improvement consisted in obtaining a greater power by a complicated force of the steam than could be obtained by its simple action in the common mode. This is effected by the use of two cylinders of different capacities. And Mr. H. after inquiring into the effect of using steam according to each of these modes, compares the results together as follows: "If we obtain the accumulated pressure by taking a mean of the extremes, we shall find Mr. Watt's application to be $\frac{24+24+12}{3} = 20$, leaving 12 lbs. at the termination of the stroke. The application of the principle in the present instance, by taking the mean of the extremes, will be $\frac{24+18}{2} = 21$, leaving 18 at the termination of the stroke; which, in point of advantage

in favour of the double cylinder, is as 3 to 2, a point of no small magnitude in the practical application of this principle, and which seems to have been overlooked by all those who have taken up the subject." Mr. Hornblower is here stated to have entered upon this project in the year 1776, and continued it until he had made a large working model, in which the cylinders were 11 and 14 inches in diameter; and that Mr. Watt's use of the expansive valve had never been put in practice until long after Mr. Hornblower had projected the design of his double engine. This gentleman also had another patent granted him for an engine having a rotary motion within itself, by the immediate action of steam on four revolving pistons, mounted on an arbor with a hollow axis.

The two improvements in the engine invented by Mr. Edmund Cartwright, are a tight piston and a condenser from which the atmospheric air is excluded. This last is made of as thin copper as the nature of its application will admit, and a large external surface is exposed to the water in order to keep it at a low temperature, so that when the steam comes in contact with it internally the condensation may be produced. An engine on this principle erected at Horseley-down is said to give great satisfaction to its proprietor, and to perform its operations effectually. For Mr. Cartwright's rotary motion, see fig. 4. pl. XXIII.

Mr. Hornblower then concludes his subject with observing that "Mr. Watt's engine, as it now stands, is the work of six-and-thirty years, and we may hold it as complete in its kind as it possibly can be. It has exercised the ingenuity of the inventor, besides frequent accessions from the ingenuity of other men: various pretensions and conceits no doubt will abound to rival its excellency, and time only, the arbiter of human affairs, will determine their fate. We would rather see a laudable competition prevail to simplify its parts, without affecting the principle, either by reducing their number, or by dispensing with their costly finish, or both, that it may come within the compass of the middle ranks as well as the more opulent; and the man who sets the example will deserve well of his country."

5. *The Edinburgh Reviewer's Account of Steam-engines.*— The honour of inventing the steam-engine is ascribed to the Marquis of Worcester, as the first idea of it is found in a small work, entitled, "*A Century of Inventions,*" published by him in 1663, and consisting of brief accounts of a number of schemes relative to inventions and improvements, which had at various times presented themselves to his mind. What relates to his contrivance, which has obtained the appellation of steam-engine, is very short and obscure; and all that can be obtained from it

is, that he had actually had a machine constructed for raising water by means of steam; but in what place or manner this was effected is probably not to be ascertained. It is supposed, that the force of this engine was derived solely from the elastic power of steam, and that the condensation of steam by cold constituted no part of his invention. This last is attributed to Captain Savery, who had erected several engines previous to the year 1696, when he published a small tract, entitled "*The Miner's Friend.*" In his engines, the alternate condensation and pressure of the steam took place in the same vessel into which the water was first raised by the pressure of the atmosphere, and then expelled by the elasticity of strong steam.

The next who effected any essential improvement in this engine was Newcomen; and for which he obtained a patent in 1705. This consisted in causing the steam to act in different vessels from those in which the water was raised; and employing the weight of the atmosphere for the purpose of pressure only, while the air was displaced by means of steam, and a vacuum produced by condensation. This was no small improvement, as it enabled him to make use of steam of much less elasticity, and therefore to work with less heat, which produced a considerable saving in the expense. To him this engine is indebted for the introduction of the steam cylinder and piston, their connexion with the pump by means of the main lever with its rods and chains, and several other inventions of less importance.

In this state, however, the engine required the constant attendance of a man to open and shut the cocks by which steam and cold water were alternately admitted, until Mr. Henry Beighton, in 1717, invented the means, or at least perfected the mechanism, for making the engine perform this operation itself. Several other of its parts were also much improved by him. No further improvement of consequence was made in the structure of this engine until the year 1764: it still continued to be styled Newcomen's, or the atmospherical engine; and was still subject to many imperfections. The steam was condensed in the cylinder; the hot water was expelled by the force of the steam; the piston was forced down by atmospheric pressure, and was kept tight by being covered with water; the injection cistern was considerably elevated, in order that water might enter with greater force. Experience had proved that the engine could only be loaded with about seven pounds for each square inch of the piston, and the great difference between this weight and that of the atmosphere was supposed to be occasioned by friction. The quantity of fuel necessary to evaporate a given quantity of water, and the quantity of steam produced from it, were alike

unknown; and whether the heat of steam corresponded exactly to its temperature, as well as the proper quantity of injection-water, for a cylinder of certain dimensions, had not been determined.

Mr. Watt, at that time a mathematical instrument maker at Glasgow, undertook the repair of the model of a steam-engine of this nature belonging to the university of that city; and in the course of his trials with it, he discovered that it required a greater quantity of both fuel and injection-water in proportion than large engines. In order to ascertain the cause of this difference, and remedy these defects, he made many experiments relative to the best materials for making cylinders; the means of producing a more perfect vacuum; the heat at which water boils under different degrees of pressure; and the quantity of water necessary to produce a given bulk of steam under the ordinary pressure of the atmosphere. These points, as well as the quantity of fuel requisite to evaporate a given quantity of water, and the quantity of cold water to be injected at each condensation of the steam, being determined with a much greater degree of precision than before, the cause of the defects in Newcomen's engine became evident. "It appeared that the steam could not be condensed so as to form an approximation to a vacuum, unless the cylinder, and the water it contained, were cooled down to less that 100°; and that, at greater degrees of heat, the water in the cylinder must produce steam, which would in part resist the pressure of the atmosphere. On the other hand, when greater degrees of exhaustion were attempted, the quantities of injection-water required to be increased in a very great ratio; and this was followed by a proportionate destruction of steam on refilling the cylinder." A consideration of these circumstances led Mr. Watt to conclude, that in order to obtain the most perfect vacuum with the least possible waste of steam, it was necessary that the cylinder should be brought to a temperature of less that 100°, and that no steam should be condensed in refilling it. Mr. Watt perceived, that to effect this the cylinder must be kept always as hot as the steam by which it was filled; and that, by opening a communication between the cylinder when full, and another vessel (which he calls a condenser) exhausted of air, the steam would rush into the condenser until the equilibrium was restored; and that if a sufficient quantity of cold water were injected into the condenser, the steam it contained would be reduced to water, and no more steam would enter until the condensation was complete. The condenser he emptied of its air and water by means of a pump, which is known by the common name of the air-pump. Some defects still remained to be remedied in Newcomen's cylinder, in

which the piston was kept tight by means of water, some of which passed by the sides of the piston, and injured the vacuum by its evaporation: this water, as well as the atmospheric air, also reduced the temperature of the cylinder considerably. "Mr. Watt removed these defects, by applying oils, wax, and fat of animals, to lubricate his piston and keep it tight: he put a cover on his cylinder (with a hole in it made air and steam tight, for the piston rod to pass through), and employed the elastic force of steam to press upon the piston; he also surrounded the cylinder with a case containing steam, or a case of wood, or of other non-conducting substance, which would keep it always of an equable temperature."

The improvements of this engine being carried to this length in Mr. Watt's mind, he executed a working model in the year 1765, which fully answered his expectations. It worked readily with a load of $10\frac{1}{2}$ lbs. for each square inch of the piston, and was even capable of raising 14 lb. per inch; and required only about one-third of the steam that was necessary in the common atmospheric engine to produce the same effect.

Mr. Watt having erected an engine on a large scale for Dr. Roebuck of Kinneil, which confirmed his previous expectations, and in which the saving of fuel exceeded two-thirds of what was used in Newcomen's engines; he then obtained a patent for his inventions in 1769; and Dr. Roebuck became associated in the prospects which it opened. Dr. R. however, soon disposed of his interest in the concern to Mr. Boulton, the founder of Soho manufactory; and the business of constructing steam-engines soon after commenced under the firm of Boulton and Watt. In reducing his inventions into practice on a large scale, Mr. Watt now made improvements in several of the parts of Newcomen's engine. He caused the cylinders to be bored with a greater degree of precision than had been previously done; "he adopted a new mode of constructing the piston and screwing down the packing, and secured the rod in the piston in a more perfect manner; he introduced puppet-valves into the steam-boxes or nozles, instead of the old sliding regulators; he used better means of opening these valves, and added various improvements in the working gear; he suspended the working beam, so that the centre of motion was below the centre of gravity, instead of being above, as in the old engines; and he improved the mode of setting the boilers on the grates, as well as the apparatus for keeping the boilers regularly supplied with water." He likewise used the steam in some of his early reciprocating engines to act expansively.

The next object that engaged Mr. Watt's attention was that of applying the power of steam to produce rotary motion; and

for this purpose he took out a patent for a steam-wheel which he had invented; but this mode was abandoned from a persuasion that this motion would be better derived from the motion of the piston in the reciprocating engine. This kind of motion, however, had been obtained in an atmospheric engine erected at Hartley coalery, in Northumberland, as early as 1768. On one end of the beam was fixed a tooth sector, which worked into a trundle, and this last, by means of two pinions with ratchet-wheels, produced a rotative motion in the same direction, by both the ascent and descent of the arch; and by changing the position of the rackets the motion could be reversed. This engine worked but very imperfectly.

In 1769, a patent was obtained by a Mr. Stewart, for an engine which produced a rotative motion, by a chain going over a pulley, and round to barrels furnished with ratchet wheels: a weight was suspended to the loose end of this chain, for the purpose of continuing the motion during the return of the engine. Mr. Washbrough's patent mode of communicating a motion of this nature, by the reciprocating strokes of the steam engine, was virtually the same as had been previously used in the engine at Hartley, with the addition of a fly; which was now used for the first time, but which had been previously thought of by Mr. Watt. It is also stated, that the idea of communicating rotative motion from the beam of the steam-engine, by means of a crank, had early occurred to Mr. Watt, but that he did not set about putting it in practice till the year 1778 or 1779, when he had a model made for that purpose, which performed to his satisfaction; and it is added, that a workman, who had been employed on the model, informed the persons engaged about one of Mr. Washbrough's engines of the contrivance. Mr. Watt then set about other modes of producing the same effect; "and, in 1781, took out a patent for several new methods of applying the vibrating or reciprocating motion of steam engines to produce a continued rotative motion round an axis, one of which was that beautiful contrivance of the revolving motion of one wheel round another. This, however, was only part of what Mr. Watt saw to be necessary, in order to perfect this application of the steam-engine. The steam had hitherto been used only to press down the piston, which was returned by a weight at the opposite end of the beam, so that the power of the steam may be said to have been inactive during that period. Mr. Watt remedied this, by applying the power of the steam to press the piston down, as well as to press it up, thus forming alternately a vacuum above and below the piston. This he called the *double engine;* and, in fact, it doubled the power exerted within the same cylinder. He had long had in his mind

the idea of this improvement; and had even produced a drawing of it to the House of Commons in 1774, at the time he procured the act to prolong his original patent; but the first he executed was, we believe, at Soho, in the year 1781 or 1782, and the first public exhibition of it at the Albion Mills a few years later *.

About the same period, finding double chains, and racks, and sectors, very inconvenient for communicating the motion of the piston-rod to the angular motion of the beam, he invented and applied what has been called the *parallel motion*, one of the most ingenious and most perfect contrivances in mechanics.

To prevent irregularities in the speed of the engine, arising from the variations in the quantum of power used at different intervals in the works to which it was applied, he made an application of the centrifugal force of what is called the governor (before used in wind and water mills), to regulate the admission of the steam; by this means keeping the engine always at a uniform velocity, and diminishing the consumption of steam in proportion to the power exerted; thus giving the finishing stroke to the perfection of the motion of this machine, and rendering its regularity nearly correspondent with that of the pendulum of a clock.

Observations.—In the perusal of these accounts (say the editors of the Retrospect), our readers will perceive, that in the former of them are mentioned the inventions of Mr. Gainsborough, for condensing the steam in a separate vessel; of Mr. Blakey, for employing the expansive force of steam; of Mr. Jos. Hornblower, for a new construction of the valve which forms a communication between the boiler and the cylinder; of Mr. Jonathan Hornblower, for obtaining a greater power by a complicated force of steam in an engine with a double cylinder; and of Mr. Edmund Cartwright, for a vacuous condenser and an improved method of packing the cylinder, which are not noticed in the latter. In the last an account is given of the original invention by the Marquis of Worcester; the improvements of Captain Savary, Newcomen, and Beighton; and of the rotatory motion at Hartley coalery, and of Stewart's patent method for the same purpose, which are not inserted in the former.

Besides the difference in these accounts, relative to the inventions of Mr. Watt, Mr. Washbrough, and others, the Reviewers, in their animadversions upon "the view which Dr. Gregory and his associate have taken of the same subject," observe re-

* I have been informed by the late Mr. H. Goodwyn, that Messrs. Boulton and Watt erected an engine of this kind at his Porter Brewery in East Smithfield, and that Mr. Rennie applied it to the different branches of the establishment there, about two years before the Albion Mills were completed.

specting Mr. Gainsborough's invention, "it is quite impossible that Mr. Watt's idea of condensing in a separate vessel could be derived from that gentleman. Mr. Watt, while he resided at Glasgow, about the year 1764 or 1765, invented that method of condensation. Mr. Gainsborough's improvement, whatever it was, was posterior by more than twenty years." Mr. Hornblower states, relative to the same subject, that Mr. Gainsborough's "model succeeded so well as to induce some of the Cornish adventurers to send their engineer to examine it; and the report was so favourable as induced an intention of adopting it. This, however, was soon after Mr. Watt had his act of parliament passed for the extension of his term; and he had, about the same time" (1774), "made proposals to the Cornish gentlemen to send his engine into that country. This necessarily brought on a competition, in which Mr. Watt succeeded." And he also adds, "it is well known that Mr. Gainsborough opposed the petition to the House of Commons, through the interest of General Conway." How this statement, and the concluding sentence of the preceding one, can be reconciled with each other, we are under the necessity of leaving to our readers to determine; we, however, cannot perceive any reason why these inventions should not have taken place independently.

When speaking of the engine for which a patent was taken out in 1781 by Mr. Jonathan Hornblower, of Penrhyn, the Reviewer says, "In the account, however, one circumstance is omitted, which is very material in the history of this engine, viz. that in the year 1799, it became the subject of an action, as an infringement of Mr. Watt's patent; and that the miners, who had used the engines of this construction, paid the portion of savings in fuel claimed by Messrs. Boulton and Watt for the use of their invention, rather than risk the event of a lawsuit. It should, besides, be observed, that if this engine merits the eulogium bestowed upon it, it seems singular, that not one of the kind has since been erected, though all legal obstructions were removed, by the expiration of Mr. Watt's patent in the year 1800." He likewise observes, that the patent granted to Messrs. Murray and Wood in 1801, for their invention of the nozles or steam-valves, and the method of opening them, was set aside in 1802 or 1803, by a writ of *scire facias*, at the instance of Boulton and Watt.

To this abridgment of the controversial papers on the history of steam-engines, it may be proper to add, that when the account of the Edinburgh Reviewers was published, Mr. Hornblower was abroad. As soon as he saw it, he complained of its "gross partiality and inaccuracy," and meant to reply to it; but

was prevented by death. We shall now proceed to describe a few approved constructions, beginning with that of Mr. Watt, of which a most perspicuous account has been given by Dr. Brewster, as follows.

6. *Watt's Steam-engine.*—Referring to pl. XXX. CD is the boiler in which the water is converted into steam by the heat of the furnace D. It is sometimes made of copper, but more frequently of iron: its bottom is concave, and the flame is made to circulate round its sides, and is sometimes conducted by means of flues even through the middle of the water, so that as great a surface as possible may be exposed to the action of the fire. In some of Watt's engines the fire contained in an iron vessel was introduced into the middle of the water, and the outer boiler was formed of wood, as being a slow conductor of heat. When the furnaces are constructed in the most judicious manner, eight square feet of the boiler's surface must be acted upon by the fire or the flame, in order to convert one cubic foot of water into steam, in the space of an hour. When fire is applied to the boiler, the water is not converted into steam till it has reached the temperature of 212° of Fahrenheit, or the boiling point. And, indeed, when the water is pressed by air or steam, more condensed than the atmosphere, a temperature greater than 212° is necessary for the production of steam: but the heat requisite for this purpose increases in a less ratio than the pressure to be overcome. The steam which is produced in the boiler is about 1800 times rarer than water, and is conveyed through the steam pipe CE, into the cylinder G, where it acts upon the piston *q*, and communicates motion to the great beam AB. But before we trace the mode of transmitting this motion, we must describe the very ingenious method employed by Mr. Watt for supplying the boiler regularly with water, and preserving it at the same level OP; a circumstance which is absolutely necessary, that the quantity and elasticity of the steam in the boiler may be always the same. The small cistern *u*, placed above the boiler, is supplied with water from the hot well *h*, by means of the pump *z*, and the pipe *f*. To the bottom of this cistern is fitted the pipe *ur*, which is immersed in the water OP, and is bent at its lower extremity, in order to prevent the entrance of the rising steam. A crooked arm *ud'*, attached to the side of the cistern *u*, supports the small lever *a'b'*, which moves upon *d'* as a centre. The extremity *b'* of this lever carries, by means of the wire *b'*P, a stone or piece of metal P, which hangs just below the surface of the water in the boiler, and the other extremity *a'* is connected by the wire *a'u* with a valve at the bottom of the cistern *u*, which covers the top of the pipe *ur*. Now, it is a maxim in hydrostatics, that when a heavy body is

suspended in a fluid it loses as much of its weight as is equal to that of the quantity of fluid which it displaces. When the water OP, therefore, is diminished by the conversion of part of it into steam, the upper surface of the body P will be above the fluid, and its weight will consequently be increased, in proportion to the quantity of the body that is not immersed. By this addition to its weight the stone P will cause the extremity b' of the lever to descend, and, in consequence, by elevating the arm $d'a'$, will open the valve at the top of the pipe *ur*, and thus gradually introduce a quantity of water into the boiler, equal to that which was lost by evaporation. This process is continually going on, while the water is converting into steam: and it is evident that too much water can never be introduced; for as soon as the surface of the water coincides with the surface of the body P, it recovers its former weight, and the valve at *u* shuts the top of the pipe *ur*.

In order to know the exact height of the water in the boiler, two cocks *k* and *l* are employed, the first of which reaches to within a little of the height at which the water would stand, and the other, *l*, reaches a very little below that height. If the water stands at the desired height, the cock *k* being opened, will give out steam, and the cock *l* will emit water, in consequence of the pressure of the superincumbent steam on the water OP, but if water should issue from both cocks, it will be too high in the boiler; and if steam issues from both, it will be too low.

As there would be great danger of the boiler's bursting if the steam should become too strong, it is furnished with the safety valve *x*, which is so loaded, that its weight, added to that of the atmosphere, may exceed the pressure of the interior steam, when of a sufficient strength. As soon as the expansive force so far increases as to become dangerous to the boiler, its pressure preponderates over the pressure of the atmosphere and the safety valve: the valve therefore opens, and the steam escapes from the boiler, till its strength is sufficiently diminished, and the safety valve shuts by the predominance of its pressure over that of the interior steam. By opening the safety valve the engine may be stopped at pleasure: and to effect this, a small rectangular lever, with equal arms, is fixed upon the side of the valve, and connected with its top; to one of these arms a chain is attached, which passes over a pulley, from a horizontal to a vertical direction, so that by pulling it the valve is opened, and the machine is stopped.

From the dome of the boiler proceeds the steam-pipe CE, which conveys the steam into the top of the cylinder G by means of the steam-valve *a*, and into the bottom of the cylinder by means of the valve *c*. The branch of the pipe which extends

from a to c is cut off in fig. 1, in order to show the valve b, but is distinctly visible in fig. 2, which is a view of the pipes and valves in the direction FM. The cylinder G is sometimes inclosed in a wooden case, in order to prevent it from being cooled by the ambient air; and sometimes in a metallic case, that it may be surrounded and kept warm by a quantity of steam which is brought from the steam-pipe EC, through the pipe EG, by turning a cock. It is generally thought, however, that little benefit is obtained by encircling the cylinder with steam, as the quantity thus lost is almost equal to what is destroyed by the coldness of the cylinder. After the steam, which was admitted above the piston q by the valve a, and below it by the valve c, has performed its respective offices of depressing and elevating the piston, and consequently the great beam AB, it escapes by the eduction valves b and d, fig. 1 and 2, into the condenser i, where it is converted into water by means of a jet playing in the inside of it. The water thus collected in the condenser is carried off, along with the air which it contains, into the hot well h, by the air-pump e, which is wrought by the piston rod TM, attached to the great beam AB. From the hot well h this water is conveyed by the pump z and the pipe f into the cistern u, for the purpose of supplying the boiler. The water w which renders air-tight the pump e, and supplies the jet of water in the condenser, is furnished by the pump g, which is worked by the great beam. The steam and eduction valves a, c, b, d, are opened and shut by the spanners aM, dM, cN, bN, whose handles M and N are moved by the plugs 1, 2, fixed to TN the piston rod of the air-pump. This part of the machinery has been called the working gear; and is so constructed that the steam and eduction valves can be worked, either by the hand or by the piston of the air-pump. The piston rod R, which moves the piston q, passes through a box or collar of leathers fixed in a strong metallic plate on the top of the cylinder. The rod is turned perfectly cylindrical, and is finely polished in order to prevent any air from passing by its sides. The top V of the piston rod R is fixed to the machinery TV, which is called the parallel joint, and is so contrived as to make the rod VR ascend and descend in a vertical or perpendicular direction. When the lever or beam rises into its present position from a horizontal one, the piston rod VR has a tendency to move towards μ, and would move towards it were the bar $\mu\nu$ fixed in its present position; for while the point V rises, the bar μV also rises, at the same time the angle V$\mu\nu$ increases, and likewise the angle λVμ, so that the vertex V of the angle λVμ would move towards T. The bar $\mu\nu$, however, is not at rest, but moves round the fixed point ν, and rises along with the point V; while $\mu\nu$, therefore,

rises upon ν as a centre, the adjoining bar μT moves round the point T towards V, the angle T$\mu\nu$ increases, and the point μ approaches to V, and keeps VR in a perpendicular position, so that whatever tendency the point V has towards T by the increase of the angle λVμ, it has an equal tendency in the contrary direction, by the increase of the angle T$\mu\nu$: but as the beam AB falls into a horizontal position, all these motions are reversed. When the piston rod VR rubs most upon the side of the collar of leathers nearest to a, the fixed point ν must be shifted a little in the contrary direction, *viz.* to the right hand of R. That the nature of this parallel joint may be better understood, it may be proper to observe, that all the bars which have been mentioned are double, as may be seen in the figure; that they move round points at λ, T, V, μ, and ν; and that the two bars between μ and V move between the bars at $\mu\nu$.

In the steam engines of Newcomen and Beighton, where the piston was raised merely by a counterweight at the extremity A of the great beam, the piston rod was connected with its other extremity by means of a chain bending round the arch of a circle fixed at B; but in Mr. Watt's improved engines with a double stroke, in which the piston receives a strong impulse upwards as well as downwards, the chain would slacken, and could not communicate motion to the beam. An inflexible rod, therefore, must be employed for connecting the piston with the beam, or the piston must be suspended by double chains like those of engines for extinguishing fire. In some of Mr. Watt's engines the latter of these methods was adopted: he then employed a toothed rack working in a toothed sector fixed at B, and afterwards fell upon the very superior method which we have now been describing.

All the engines which were constructed before the time of Mr. Watt were employed merely for raising water, and were never used as the first movers of machinery; except indeed that Mr. R. Fitzgerald published, in the Transactions of the Royal Society, a method of converting the irregular motion of the beam into a continued rotatory motion, by means of a crank and a train of wheel-work connected with a large and massy fly, which, by accumulating the pressure of the machine during the working stroke, urged round the machinery during the returning stroke, when there is no force pressing it forward. For this new and ingenious contrivance Mr. Fitzgerald received a patent, and proposed to apply the steam-engine as the moving power of every kind of machinery, but it does not appear that any mills were erected under this patent. In order to convert the reciprocating motion of the beam into a circular motion, Mr. Watt fixed a strong and inflexible rod AU to the extre-

mity of the great beam. To the lower end of this rod a toothed wheel U is fastened by bolts and straps, so that it cannot move round its axis. This wheel is connected with another toothed wheel S of the same size, by means of iron bars, which permit the former to revolve round the latter, but prevent them from quitting each other. This apparatus is called the sun and planet wheels, from the similarity of their motion to that of the two luminaries. On the axis of the wheel S is placed the large and heavy fly-wheel F, which regulates the desultory motion of the beam. When the extremity A of the great beam rises from its lowest position, it will bring along with it the wheel U, and cause it to revolve upon the circumference of the wheel S, so that the interior part of the former, or the part next the cylinder, will act upon the exterior part of the latter, or the part farthest from the cylinder, and put it in motion along with the fly F. After the wheel U has got to the top of the wheel S, the end A of the beam will have reached its highest position, and the wheel S, along with the fly, will have performed one complete revolution. When the wheel U passes from the top of S into its former position below it, the extremity A of the beam will also descend from its highest to its lowest position, so that for every ascent or descent of the piston or the great beam, the planet-wheel U will make one turn, while the sun-wheel and fly will perform two complete revolutions.

When the steam-engine is employed to drive machinery in which the resistance is very variable, and where a determinate velocity cannot properly be dispensed with, Mr. Watt has applied a conical pendulum, which is represented at *mn*, for procuring a uniform velocity. This regulator consists of two heavy balls *mn*, suspended by iron rods which move in joints at the top of the vertical axis *op*, and is put in motion by the rope *oo* which passes over the pulleys *o*, *o*, and round the axis *o* of the fly. Since the velocity of the fly and sun-wheel increases and diminishes with the quantity of steam that is admitted into the cylinder, let us suppose that too much is admitted,—then the velocity of the fly will increase, but the velocity of the vertical axis *op* will also increase, and the balls *mn* will recede from the axis by the augmentation of their centrifugal force. By this recess of the balls, the extremity *p* of the lever *ps*, moving upon *y* as a centre, is depressed, its other extremity *s* rises, and by forcing the cock at *a* to close a little, diminishes the supply of steam. The impelling power being thus diminished, the velocity of the fly and the axis *op* decreases in proportion, and the balls *m*, *n*, resume their former position.

In Mr. Watt's improved engine, the steam and eduction-valves are all puppet clacks. One of these valves, and the method of opening and shutting it, is represented in fig. 3 of Plate XXX. Let it be one of the eduction-valves, and let AA be part of the pipe which conducts the steam into the cylinder, and MM the superior part of the pipe which leads to the condenser. At oo, the seat of the valve, a metallic ring, of which *nn* is a section, is fitted accurately into the top of the pipe MM, and is conical on the outer edge, so as to suit the conical part of the pipe. These two pieces are ground together with emery, and adhere very firmly when the contiguous surfaces are oxydated or rusted. The clack is a circular brass plate *m*, with a conical edge ground into the inner edge of the ring *nn*, so as to be air-tight, and is furnished with a cylindrical tail *m*P, which can rise or fall in the cavity of the cross bar NN. To the top of the valve *m* a small metallic rack *m*F is firmly fastened, which can be raised or depressed by the portion E of a toothed wheel, moveable upon the centre D. The small circle D represents a section of an iron cylindrical axis, whose pivots move in holes in the opposite sides of the pipe AA. Its pivots are fitted into their sockets, so as to be air-tight; and the admission of air is farther prevented by screwing on the outside of the holes necks of leather soaked in rosin or melted tallow. One end of this axis reaches a good way without the pipe AA, and carries a handle or spanner *b*N, which may be seen in fig. 1. Plate XXX. and which is actuated by the plugs 1, 2, of the rod TN. When the plug 2, therefore, elevates the extremity of the spanner N*b*, during the ascent of the piston-rod TN, the axle D, Plate XXX. fig. 3, is put in motion, the valve *m* is raised by means of the toothed racks E and F, and the steam rushes through the cavity of the circular ring *nn*, by the sides of the cross piece of metal oo, NN. When the valve needs repair, the cover B, which is fastened to the top of the valve box by means of screws, can easily be removed.

Having thus described the different parts of the most improved steam-engine, it will be proper to attend to the mode of its operation. Let us suppose that the piston is at the top of the cylinder, as is represented in the figure, and that the upper steam valve *a*, and the lower eduction or condensing valve *d*, are opened by means of the spanner M, while the lower steam valve *c*, and the upper eduction valve *b*, are shut; then the steam in the boiler will issue through the steam pipe CE, and the valve *a*, into the top of the cylinder, depress the piston, by its elasticity, to the very bottom. But when the piston *q* is brought to the bottom of the cylinder, and the extremity B of the great beam is dragged down by the parallel joint TV, its

other extremity A rises, and the wheel *u* having passed over half of the circumference of *s*, will have urged forward the fly-wheel F, and consequently, the machinery attached to it, one complete revolution. When the piston *q* has reached the bottom of the cylinder, the piston-rod TN of the air-pump, by the pressure of the plug 1 upon the spanner M, has shut the steam valve *a* and the eduction valve *d*, while the plug 2 has, by means of the spanner, opened the eduction valve *b*, and the steam valve *c*. The steam, therefore, which is above the piston, rushes through the eduction valve *b* into the condenser *i*, where it is converted into water by the jet in the middle of it, and by the coldness arising from the surrounding fluid *w*, while, at the same time, a new quantity of steam from the boiler issues through the open steam-valve *c*, into the cylinder, forces up the piston, and, by raising one end of the working beam, and depressing the other, makes the wheel U describe the other semi-circumference of S, and causes the fly and the machinery on its axis to perform another complete revolution. As the plugs 1, 2, ascend with the piston *q*, they open or shut the steam and eduction valves, and the operation of the engine may be thus continued for any length of time.

From this brief description of the steam-engine, the reader will be enabled to perceive the nature and appreciate the value of Mr. Watt's improvements. It had hitherto been the practice to condense the steam in the cylinder itself, by the injection of cold water: but the water which is injected acquires a considerable degree of heat from the cylinder, and being placed in air highly rarefied, part of it is converted into steam, which resists the piston, and diminishes the power of the engine. When the steam is next admitted, part of it is converted into water by coming in contact with the cylinder, which is of a lower temperature than the steam, in consequence of the destruction of its heat by the injection water. By condensing the steam, therefore, in the cylinder itself, the resistance to the piston is increased by a partial reproduction of this elastic vapour, and the impelling power is diminished by a partial destruction of the steam which is next admitted. Both these inconveniences Mr. Watt has in a great measure avoided, by using a condenser separate from the cylinder, and encircled with cold water*; and by surrounding the cylinder with a wooden case, and interposing light wood ashes, in order to prevent its heat from being abstracted by the ambient air.

* Even in Mr. Watt's best engines, a very small quantity of steam remains in the cylinder, having the temperature of the hot-well *p*, or of the water, into which the ejected steam is converted. Its pressure is indicated by a barometer, which Mr. Watt has ingeniously applied to his engines for exhibiting the state of the vacuum.

The greatest of Mr. Watt's improvements consists in his employing the steam both to elevate and depress the piston. In the engines of Newcomen and Beighton, the steam was not the impelling power; it was used merely for producing a vacuum below the piston, which was forced down by the pressure of the atmosphere, and elevated by the counter-weight at the farther extremity of the great beam. The cylinder, therefore, was exposed to the external air at every descent of the piston; and a considerable portion of its heat being thus abstracted, a corresponding quantity of steam was of consequence destroyed. In Mr. Watt's engines, however, the external air is excluded by a metal plate at the top of the cylinder, which has a hole in it for admitting the piston-rod; and the piston itself is raised and depressed merely by the force of steam.

When these improvements are adopted, and the engine constructed in the most perfect manner, there is not above $\frac{1}{4}$ part of the steam consumed in heating the apparatus; and, therefore, it is impossible that the engine can be rendered $\frac{1}{4}$ more powerful than it is at present. It would be very desirable, however, that the force of the piston could be properly communicated to the machinery without the intervention of the great beam. This, indeed, has been attempted by Mr. Watt, who has employed the piston-rod itself to drive the machinery; and Mr. Cartwright has, in his engine, converted the perpendicular motion of the piston into a rotatory motion, by means of two cranks fixed to the axis of two equal wheels which work in each other. Notwithstanding the simplicity of these methods, none of them have come into general use, and Mr. Watt still prefers the intervention of the great beam, which is generally made of hard oak, with its heart taken out, in order to prevent it from warping. A considerable quantity of power, however, is wasted by dragging, at every stroke of the piston, such a mass of matter from a state of rest to a state of motion, and then from a state of motion to a state of rest. To prevent this loss of power, a light frame of carpentry has been employed by several engineers instead of the solid beam. Cast iron beams have been adopted with great success. *(Brewster's Ferguson.)*

7. Pl. XXXI. fig. 1, represents a STEAM-ENGINE, erected in 1802, by Messrs. *Murray* and *Wood* of Leeds, for Mr. *Francis Brewin*, at his tan-yard in Willow Walk, Bermondsey; and fig. 2. represents some parts on a larger scale: AA is the shaft for conveying the power of the engine to work a bark-mill and several pumps. The steam from the boiler enters through the pipe B into the assemblage of pipes, technically termed *nossels* or *valve-boxes*, represented separately in fig. 2,

which contain the valves for distributing the steam at proper intervals into the cylinder CC, and letting the same off again to the condenser M. The cylinder CC, which is cased with wood to keep in the heat, has a solid piston moving in it, whose polished *piston-rod* D passes through a stuffing-box; the upright motion of this rod is converted into a rotatory one by the following contrivance: the circular rim E, three feet diameter, with seventy-two teeth on the inside, is firmly fixed and suspended from the floor, by two cast-iron pillars FF and braces LL; the small wheel G, of eighteen inches diameter and thirty-six teeth, is made to revolve within-side of the rim, so as always to touch the teeth by a pin (the end of which is represented in the centre of the wheel G), firmly fixed on the wheel H, parallel to its axis AA, with which it always moves; and nine inches from its centre, on the circumference of the wheel G, is a bolt I, screwed on perpendicular to its plane, in such a place, that when the wheel G is at the bottom of the rim E, the bolt is on the lowest tooth; and when the small wheel is at the top of the rim, it is on the highest: to this bolt the piston-rod D and the air-pump-rod K are attached, and the tops of these rods, by moving up and down in right lines, passing through the axis of the wheel H, will communicate a rotatory motion to that wheel, and all on the same shaft. See the article PARALLEL *Motion*.

The wheel *a*, on the axis AA of the fly-wheel NN, communicates its motion by the wheels shown in fig. 2, to the wheel *b*; which wheels are so contrived, that one revolution of the fly will produce one of the wheel *b*, on whose axis are two eccentric wheels *c* and *d*, which alternately raise the rods *e* and *f*, for opening the valves contained in the short cylinders or valve-boxes *gg* and *hh*: each of these boxes has three divisions; the upper division of the upper box contains a valve 1, called the *upper steam-valve*; its use is to admit steam from the boiler through the pipe B, into the middle division which communicates with the cylinder; in this box is a valve 2 (which is moved by a rod passing through the rod of the other valve 1), called the *upper condensing-valve* (or *exhausting-valve*); it is for opening a passage from the top of the cylinder to the condenser by the pipe *q*. In the same manner, the upper valve 3 of the lower box is called the *lower steam-valve*, and is for admitting steam in the lower part of the cylinder by means of the pipe *r*; the valve 4 is for connecting the bottom of the cylinder with the condenser, and is therefore called the *lower condensing-valve*. The rod *f* connects at its top with the *upper condensing-valve* (2), and the *lower steam-valve* (3) at its bottom; it will, therefore, when it is lifted up by the eccentric wheel *d*, open those

valves, and by causing a vacuum above, and a pressure of steam beneath, the piston, force it upwards and move the machinery: also the rod *e*, connecting with the *upper steam valve* I at its top, and the *lower condensing-valve* 4 at its bottom, being lifted up by the eccentric wheel *c*, will cause the piston to descend; but this will not be the case, unless one rod is permitted to descend by its own weight, as the other is lifted; otherwise the steam will leave free passage from the boiler to the condenser, which operation is called *blowing through*.

The condenser M is a cylindric vessel, into which is admitted a small jet of cold water, by the cock *l*, called the injection-cock: the bottom of the condenser communicates by a short pipe O (which pipe contains a valve shutting towards the condenser), with the *air-pump* P, four inches diameter and three feet stroke; the piston of the air-pump has a valve in it, and is moved by the rod K, as before described; the air-pump's office is to extract the water of the condensed steam, injection, &c. from the condenser, and keep the vacuum perfect. The air pump and condenser must be in a well or cistern of cold water.

To work this engine, the steam must be made of sufficient elasticity to rush forcibly out of the boiler when permitted; draw the handles *n* and *o* apart from each other, which acting as levers against the stubs on the rods *e* and *f*, will raise them up in a small degree, and open all the valves at once; and the steam, by *blowing through*, will expel the water, air, &c. which may have filled the cylinder and condenser, at a valve shutting outwards in the condenser for that purpose. When it is thought that the air, &c. is all driven out, one or other of the handles must be dropped (according to the position of the wheel G); the injection cock *l* is then opened by its handle *p*, which suddenly cooling the steam, reduces it to the bulk it formerly possessed in the boiler, and forms a vacuum in the condenser; the steam from the cylinder which rushes in to restore the equilibrium is condensed as it goes, and almost instantaneously a nearly perfect vacuum is formed on one side of the piston; and the steam from the boiler pressing on the other, destroys the equilibrium on it, and puts the engine in motion. When the piston is at the top of its stroke by the arrangement of the wheels in fig. 2, the eccentric wheel *c* will lift the rod *e* (at the time the rod *f* is permitted to descend by its weight), and cause the piston to descend; and when at the bottom of the rod *f* will be lifted, and *e* will fall, which forces it upwards again.

To stop the engine, nothing is necessary but to lift up both the handles and shut the injection-cock (which should always be shut when the engine is not at work), to prevent the con-

denser from filling with water; and as soon as the momentum of the fly-wheel is spent, the motion of the engine will cease; it might also be stopped by only cutting off the injection, which would, after a considerable number of strokes, render the vacuum so imperfect as to destroy its power.

The cylinder of this engine is twelve inches diameter, and has a three-feet stroke; its power is computed at four horses, it makes about fifteen strokes per minute, and burns about nine bushels of coals in fourteen hours, being the usual period of working.

---

8. M. *Bettancourt*, whose curious and valuable experiments on the expansive force of steam are duly appreciated by philosophers, has contrived some steam-engines of double effect; one of which being very simple and ingenious, may here be described, at least all which is peculiar to it. See fig. 3. pl. XXXI. The steam coming in the ordinary way from the boiler, which is omitted to render the design more simple, passes through the tube b, and introduces itself by the aperture v into the space of which the circle ee' represents the profile or vertical section. This chamber $e\,e'$ has, besides the orifice v, two others, the one placed by the side of the canal d, to communicate by means of that canal with the superior part B of the cylinder BB; the other placed below at v', and communicates by means of the tube or canal $v'\,d$, with the inferior part B′ of the cylinder, of which the piston is represented in X. The space, or circular chamber $e''\,e'''$, communicates in a similar manner with the upper and lower parts of the cylinder, by means of the tube $v''\,d$, and the canal d'. Moreover, this chamber $e''\,e'''$ communicates by means of the orifice v''' with the chamber ff', where the valve j is found adapted to the aperture through which issues the water of injection destined to condense the vapour: this valve is always open, except when we would stop the machine; but it may approach the orifice more or less, according to the velocity which we would give to the piston. The outlets v and v''' are, in like manner, always open.

The orifices v', v'', and those which establish the communication with the cylinder by means of the canals d and d', are closed alternately by the valves gh, or $g'h'$ of a particular kind. Fig. 3. no. 2. represents the profile of either of these valves. The part gh curved into the arc of a circle of the same radius as that of the vertical sections ee', $e''\,e'''$, and turning upon an axis placed at the centre o, may in its revolution close any aperture whatever placed upon the circumference of those sections.

This being understood, suppose things in the state represented in fig. 3. no. 1. and the vacuum established in the part of the cylinder above the piston. The steam entering by the orifice *v*, finds the canal *d* closed, passes through the tube $v' \, d'$, but cannot introduce itself into the chamber $e'' \, e'''$ because of the valve $g' \, h'$; it therefore enters wholly into the lower part B′ of the cylinder. Hence it acts upon the piston X with all the energy of which it is capable: the piston pushes the great beam by means of the piston-rod XK, and the opposite part of that beam acts with a like effort upon the rod or bar destined to give the rotatory motion to the fly. The piston X having thus arrived at the highest point of its course, the valve $g' \, h'$ makes a part of a rotation, so as to close the orifice v'', and open the canal d'; in the same time the valve *gh* makes part of a revolution likewise, to close the aperture v' and open the canal *d*. The aqueous gas continuing to enter at *v*, which is constantly open, finds the orifice v' closed, penetrates into the canal *d*, and not having any passage through the orifice v'', goes entirely into the upper part of the cylinder: during this time, the steam which was in B′ is expelled through d', penetrates into v''', which is always open, and becomes condensed about the valve *j*. By these means the steam which enters B, acting with all its energy upon the piston X, makes it descend, and produces, by descending, equal effects to those it caused when ascending. The piston, then, having arrived at the lowest point of its course, the valve *gh* which closed the orifice v', and the valve $g' \, h'$, which closed the orifice v'', return both to their primitive situation; and so on throughout.

The extent of the stroke of the piston must manifestly be such that the apertures of the canals at *d*, and d', placed in the side of the cylinder, are never stopped by the piston.

It is almost needless to say, that the interior mechanism relative to the valves *gh*, $g' \, h'$, may be moved by various contrivances, each depending upon the alternating motion of the piston: so that no other agent will be required distinct from the machinery, than what are wanted for keeping up the fire.

---

9. In the course of the last 20 years, there has scarcely been a month in which some new modification of the steam-engine has not been proposed. To detail all these is impossible. We shall simply specify, in addition to what has already been presented, some of the recent inventions of Mr. *R. Witty*, of Hull.

In February 1810, this mechanist took out a patent for *rota-*

tive steam-engines, the revolving motion of which was effected by weights alternately drawn to and driven from a centre, round which a working cylinder or cylinders revolved; and to the opposite ends of the piston rod or rods, that passed through the said cylinder or cylinders, the weights were attached. Improvements on these engines, for which a patent was taken in October, 1811, Mr. Witty states to consist in making the piston draw or force round the machinery to be worked by it, whilst itself moves both in a rectilinear and rotatory direction in a cylinder or steam vessel; which also *revolves upon an axis*, placed either in a horizontal, vertical, or oblique position. The mechanical contrivances by which this is effected are of various kinds, which cause the power of the piston to draw or force the cylinder round; and move the mill-work, or machinery, which is attached to the engine, by the revolution of the axis or shaft of the revolving cylinder, or by the piston-rod being made to act upon a wheel, or other contrivance, upon a separate axis or shaft, fixed or otherwise as ocasion may require.

To admit the action of the steam, and of the condenser, in the revolving cylinder, its axis is bored lengthwise in two places so as to form two passages, each of which communicates by lateral pipes with the end of the cylinder opposite to the side of the axis in which it lies; the extremity of this perforated axis is formed of a conical shape, and turns in a box made to fit it, in the same manner that the revolving part of a common cock turns in its barrels; from the upper part of this box a pipe passes to the steam boiler, and from the lower part another pipe proceeds to the condenser, and lateral apertures are made through the sides of the axle to the two passages within it before-mentioned, which, as the axle turns, alternately communicate with the steam pipe, and the pipe of the condenser in the box, in the same way as a cock with two ways acts; with which cock this part of the engine is on the same principle. The axle projects through the box, and has a crank at its end, by which it works the air-pump of the condenser.

Several principles are mentioned by the patentee, on which the cylinder, prepared as described, can force itself round; which are all of the nature of crank or cardioid motions: both of which, however, may be referred to one source, as they are caused by an apparatus made to protrude and retract alternately between two centres, one of which revolves, and the other is fixed.

The first of these principles stated by the patentee, (which he calls a cardioid motion, though it is more properly a crank motion,) effects the rotatory movement by the action of a moving groove on a fixed centre; which groove is placed at right angles

to the cylinder, in a frame that is connected with piston-rods proceeding from the opposite ends of the cylinder, and of course partakes of their alternating motion.

The second principle consists of the operation of the ends of piston-rods, proceeding from the opposite extremities of the cylinder, on the outside of the rim of a large wheel, whose centre is placed at the distance of about half the stroke of the piston from the axis of the cylinder. The rim of the wheel projects so as to extend to the line of the piston-rods, which are bent round to support friction-wheels outside it, that alternately come in contact with steps on the rim, and by them force round the wheel, by a cardioid motion; or, in other words, by a motion similar to that which levers would cause, when made to press alternately on the outside of a heart-wheel.

The third principle is a variety of the second, and consists in making the large wheel before-mentioned revolve on a ring, supported by friction-wheels, which includes within its circumference the axle of the revolving cylinder. A species of this last mode is mentioned by the patentee, that deserves particular notice, in which the ring is large enough to include within it the cylinder and protruded piston-rods, and is to be placed in the plane of the piston-rods, and at right angles to the axis of the cylinder.

The fourth principle consists in the action of the piston-rods, arranged, as first mentioned, against the inside of a heart-shaped ring, placed vertically with its apex downwards, one half of which ring is moveable outwards by being suspended from a hinge at its upper end. The axis of the revolving cylinder is placed in one of the centres of this cardioid-ring; and the ends of the piston-rods, furnished with friction-wheels, press alternately on the fixed and on the moveable sides of the ring, and thus produce the rotative motion.

A fifth mode, mentioned by the patentee as a variety of the first, deserves to be noticed by itself for its greater simplicity: it consists of a crank a quarter the length of the stroke, or a fixed centre placed at that distance from the axis of the cylinder, from which a rod passes to the top of the piston-rod. In this method, and also in the first, a strong iron knee proceeds from the fixed centre to support the gudgeon-end of the axis of the revolving cylinder, or that end which is opposite to its perforated extremity. The end of this knee next the fixed centre is driven tight into a piece of cast-iron and keyed fast, which piece is bolted down to a beam of wood that supports it. The fixed centre lies between the angle of this knee and its support.

The advantages of steam-engines, constructed on these principles, over common engines, the patentee mentions to consist

in saving the power lost in the motion of heavy engine-beams, parallel apparatus, valves, hand-gear for moving valves, and plug-frames, none of which are used in his engines; and in the great simplification of machinery, which arises from their removal. The patentee also states, that the ponderous fly-wheel, used to regulate the motion in other engines, may in his be in a great measure dispensed with.

The editor of the "Retrospect," from the thirty-second number of which the preceding account of Mr. Witty's contrivances is taken, adds,

"When any good method is adopted for preventing the tendency to bend the piston, which an arm at right angles used to force round the engine would occasion, in the manner before explained, then the fifth or last method described would seem to be preferable to most of the others, on account of its greater simplicity, and its having less friction than them.

"On the contrary, the method in which the grooved frame is used seems the worst, on account of the binding, or increased friction, which grooves acted on by oblique impulses always undergo, especially when the degree of the obliquity approaches so very near a direction perpendicular to the groove, as it does on this occasion; which, added to the defect before stated, would occasion a very great waste of the force of the engine.

"Of all the methods, however, in the state in which they are described by the patentee, those two, in each of which the cylinder revolves within a ring that surrounds it in the plane of the piston-rod, at right angles to the axis of the revolving cylinder, appear the most advantageous; because in them less of the force is lost in oblique movements, and the piston-rods suffer no injury from any part of the machinery tending to produce lateral impulses.

"Of these two methods, that with the revolving ring appears to be preferable, from its causing less friction, and producing a more free motion; and as the revolving ring might be likewise made to perform the office of a fly-wheel, it would also be simpler. A mode (not mentioned by the patentee) of applying the smaller ring, that extends only far enough to include the axis of the cylinder, and is described first in the account of the third principle of the patent, seems also preferable to the fixed ring, and nearly if not fully equal to the revolving ring, from the simplicity of construction of which it renders the engine capable.

"The advantages stated by the patentee, that engines on these principles possess in comparison with others, seem in most respects justly represented: but, on the other hand, it must be observed that there is much more force lost, in even

the best of the methods proposed, from the obliquity of the impulse of the moving power to the motion produced, than in the beam engine and crank; as the latter acts in two points of the revolution at right angles to the crank, or in the direction of the motion produced, which is the most advantageous direction; while in none of the plans proposed by the patentee does the impulse come much nearer the direction of the produced motion, than what would form with it an angle of forty-five degrees.

"We must differ from the patentee also, as to the capability which he supposes his engines afford of dispensing with fly-wheels; thinking, on the contrary, that from the great variation of the force producing the rotary motion, in various parts of the revolution (on account of the great difference in the obliquity of its direction) the fly-wheel would be absolutely necessary to produce equable rotative motion in them.

"But notwithstanding that some loss of force would be caused by the obliquity of the impulse to the direction of the motion (as before mentioned), we think that very useful and powerful engines may be formed on the principles invented by the patentee, when they obtained those modifications, which practice and experience in constructing them will point out; and that next to Mr. Mead's plan for a rotative steam engine, these of the patentee are by far the most ingenious yet laid before the public. We also think, that in point of simplicity, and in the facility of their being kept in order, and having the stuffing kept tight, and renewed when wanted, they are superior to Mr. Mead's engine: and that the species of them which revolves with a simple crank motion, and that with the larger outside revolving ring, if not some of the other kinds, may be afforded at a considerably lower price than Mr. Mead's, or, when the mode of making them is brought to perfection, than most other steam-engines, on account of the number of parts and the quantity of framing used in other engines, that may be omitted in their construction."

10. *The theory of steam-power in reference to the mechanical energy of engines* is as yet in a very imperfect state. The best formulæ which we have hitherto seen are exhibited by Mr. *Tredgold*, in his judicious and valuable work on *Rail-roads*. As they are found to furnish results which agree very nearly with those of experiment, we shall insert them here.

If f be the measure of the force of steam in inches of the mercurial column, and t the corresponding temperature measured on Fahrenheit's thermometer; f' the resistance from the friction of the steam piston, and the uncondensed vapour in the cylinder, or the atmospheric pressure in high-pressure engines, and n the bulk or capacity of the steam cylinder, when

the bulk of the steam admitted at the pressure f is unity. Then the power of the steam generated from a cubic foot of water is

$$4873\ (459 + t) \times (1 - \frac{nf'}{f}) + \text{hyp. log. } n).$$

When the steam does not act by expansion $n = 1$.

When the expanding force of the steam is employed, the above equation has a maximum, which will obtain when hyp. log. $n - \frac{nf'}{f}$ is a minimum, which is evidently the case when $n = \frac{f}{f'}$.

In that case, inserting $\frac{f}{f'}$ for n, we have

$$4873\ (459 + t) \cdot (\text{hyp. log. } \frac{f}{f'} =$$

the maximum power of a cubic foot of water converted into steam.

When $f = f'$, then hyp. log. $\frac{f}{f'} = 0$, and the power is nothing.

And, when $1 - \frac{f'}{f}$ is greater than hyp. log. $\frac{f}{f'}$ it is disadvantageous to work by expansion.

11. To calculate the quantity of fuel, let c be the quantity which converts a cubic foot of water into steam that will bear the preasure of the atmosphere; let s be the specific heat of the steam, a the specific heat of the air and smoke which escape up the chimney, and w the weight of fuel that will heat one cubic foot of water one degree: then

$$c + [(t - 212^\circ) \times (a + s)\ w] =$$

the least quantity of fuel that will produce steam of the force f and temperature t.

Mr. *Tredgold*, by assuming $c = 8{\cdot}4$ lbs. of Newcastle coals, $w = {\cdot}0075$ lbs., $s = {\cdot}847$, and $a = {\cdot}753$, reduces the preceding to $8{\cdot}4 + {\cdot}012\ (t - 212^\circ) =$ the lbs. of coal to produce steam of the temperature t.

12. For a high-pressure engine, taking 30 inches for the measure of atmospheric pressure, $\frac{1}{5}$ of the pressure of the steam for the friction of the steam piston, and $\frac{1}{20} f$ for the plus pressure in the boiler, the whole loss becomes $\frac{1}{4} f$. But one side of the piston of a high-pressure engine is acted upon by the same pressure as that of the external atmosphere: hence $f' = \frac{1}{4} f + 30 =$ the resistance to the moving force f.

Consequently, when a high-pressure engine is worked expansively, we have

$$4873\ (459 + t) \times (\text{hyp. log. } \frac{f}{\frac{1}{4} f + 30}) =$$

the mechanical power of a cubic foot of water converted into steam.

Hence there is no advantage in making a high-pressure

steam-engine work expansively, when the force of the steam is less than 60 inches of the mercurial column; because the above hyp. log. is then less than $1 - \frac{\frac{1}{4}f + 30}{f}$.

When an engine does not employ the expansive power of steam, we have

$$4873\ (459 + t) \times (1 - \frac{\frac{1}{4}f + 30}{f}) =$$

the mechanical power of a cubic foot of water converted into steam.

Mr. *Tredgold* illustrates these formulæ by the following example: Let the force of the steam be 120 inches of mercury; the corresponding temperature is 292·8°. Then

$$4873\ (459 + 292{\cdot}8) \times (1 - \frac{(\frac{1}{4} \times 120) + 30}{120}) =$$

1,830,000 lbs. raised one foot high.

The quantity of coal is $8{\cdot}4 + {\cdot}012\ (292{\cdot}8 - 212) =$ 9·37 lbs. of coal.

Now if the horse power be 16,000,000 lbs. raised one foot in a day of 8 hours, then

1,830,000, : 9·37 lbs. : : 16,000,000 : 82 lbs.

Therefore, working with steam of $44\frac{1}{2}$ lbs., on the square inch on the piston, above the pressure of the atmosphere, 82 lbs. of Newcastle coal ought to do the day's work of a horse.

But if the engine works expansively with the same force of steam, then

$$4873\ (459 + 292{\cdot}8) \times (\text{hyp. log. } 2) = 2{,}540{,}000 \text{ lbs.}$$

raised one foot high by 9·37 lbs. of coal; and consequently 59 lbs. of coal ought to do the day's work of a horse.

13. With regard to the maximum of useful effect in steam-engines, it will be found, according to Mr. *Tredgold*, by taking $v = 120\sqrt{l}$, for the working velocity of an engine in feet per minute, l being the length of the stroke in feet.

If an engine has a 2 feet stroke, then $v = 170$ feet per minute, and the number of strokes per minute $42\frac{1}{2}$.

By increasing the stroke to 3·4 feet we get a velocity of 220 feet per minute, with 32 strokes per minute.

If any variation be made from the maximum power, the decrease of effect is the same as in horse power; but, as Mr. T. remarks, we have this advantage in an engine; it can be made for any velocity, by attending to the relative proportions of its parts; those of a horse we cannot alter.

14. A horse, when he treads a mill-path at the rate of $2\frac{1}{2}$ miles an hour, will on an average raise about 150 lbs. by a cord hanging over a pulley; which is equivalent to 33,000 lbs. one foot high in an hour. *Boulton* and *Watt* estimate this at 32,000; *Tredgold*, still lower, at 27,500. Taking the first measure,

however, as a basis of comparison; putting d for the diameter of the piston in inches, p for the pressure of the steam upon each square inch (diminished usually by about $\frac{1}{5}$ for friction and inertia), l for the length of the stroke of the piston in feet, n for the number of strokes in a minute: then, the power of the engine in "horse-powers," (HP), is

$$\left.\begin{array}{l}(HP) = \cdot 0000238\, d^2\, n\, p\, l, \text{ if it be a single stroke} \\ (HP) = \cdot 0000476\, d^2\, n\, p\, l, \text{ if it be a double stroke}\end{array}\right\} \text{engine.}$$

Example.—Suppose $d = 20$ inches, $l = 3$ feet $n = 36$, $p = 50$, and the engine one of double stroke. Then $\cdot 0000476 \times 20^2 \times 36 \times 50 \times 3 = 102\cdot 816$, or nearly 103 horse-powers, the measure of the energy of the engine.

Mr. *Boulton* states that 1 bushel of Newcastle coals, containing 84 pounds, will raise 30 million pounds 1 foot high; that it will grind and dress 11 bushels of wheat; that it will slit and draw into nails 5 cwt. of iron; that it will drive 1000 cotton spindles, with all the preparation machinery, with the proper velocity; and that these effects are equivalent to the work of 10 horses.

15. The rule usually given to adjust the weight of the *fly-wheel* is this: Multiply the number of *horse-powers* in the machine by 2000; divide the product by the square of the velocity in feet, per second, of the fly's circumference; the quotient will give its weight in hundredweights.

$$\text{Or, } 2000\,(HP) \div \left(\frac{\pi\, d\, n}{60}\right)^2 = \text{weight of fly.}$$

Thus, suppose the fly-wheel of a 20 horse-power engine to be 18 feet diameter, and to revolve 22 times in a minute; what should be its weight?

Here, $\frac{18 \times 3\cdot 1416 \times 22}{60} = 20\frac{1}{2}$ feet nearly, velocity of circumference per second.

Whence $\frac{20 \times 2000}{(20\frac{1}{2})^2}$ $90\cdot 4$ cwt. of the fly-wheel required.

It is much to be regretted that in the country where all the great and essential improvements in steam-engines have been made, and where so noble a species of mechanism was invented, there is no sufficiently copious treatise on their construction and history. What is here given is a mere collection, correct, it is hoped, but very limited. They who wish to go farther into this interesting inquiry may turn to the article STEAM-*engine* in the *Encyclopædia Britannica*, the *Pantologia*, and *Brewster's Ferguson's Lectures*; to the successive volumes of the *Repertory of Arts and Manufactures*, to the 2d volume of Prony, *Architecture Hydraulique*, and to Hachette, *Traité des Machines*, and the Histories of the Steam Engine by *Partington* and *Stuart*,

both of which, considering their limits, are instructive and interesting.

STEAM-*boats*.—One of the earliest projects, to apply the force of steam to the purpose of propelling boats, was in 1736, when a patent was taken out for a boat to be moved by steam. The next was that of Mr. Symington. In his boat, by placing the cylinder nearly in a horizontal position, the introduction of a beam is avoided. The piston is supported in its position by friction-wheels, and communicates, by means of a joint, with a crank, connected with a wheel, which gives the water-wheel, by means of its teeth, a motion somewhat slower than its own: the water-wheel serving also as a fly. This water-wheel is situated in a cavity near the stern, and in the middle of the breadth of the boat, so that it becomes necessary to have two rudders, one on each side, connected together by rods, which are moved by a winch near the head of the boat, so that the person who attends the engine may also steer.

Mr. Symington has likewise placed an arrangement of stampers at the head of the boat, for the purpose of breaking the ice on canals, an operation often attended with great labour and expense. These stampers are raised in succession by levers, the ends of which are depressed by the pins of wheels turned by an axis communicating with the water-wheel. A drawing of this steam-boat is given by Dr. Young in the 1st vol. of his Natural Philosophy.

Steam-boats are now very numerous on the British coasts and principal rivers. The following account of the steam-boats on the Clyde, by Mr. Robertson Buchanan, of Glasgow, was published in No. 203. of Tilloch's Philosophical Magazine.

"So early as the year 1801, a vessel propelled by steam was tried on the Forth and Clyde inland navigation, but was laid aside, among other reasons, on account of the injury it threatened the banks of the canal by the agitation of the water: and as far as I can learn, the same objection still subsists to the use of steam-boats on artificial canals so narrow as those usual in Great Britain. That objection, however, I should think, does not apply to some of those of Holland and other countries on the continent.

"The first attempt on any scale worthy of notice, to navigate by steam on the river Clyde, was in the year 1812 *. A passage-boat of about 40 feet keel and 10½ feet beam, having a steam-engine of only three horses' power, began to ply on the

* The first steam-boat in America was launched at New York on the 3d of October 1807, and began to ply on the river between that city and Albany, a distance of about 120 miles.

river. Since that period the number of boats has gradually increased.

"Besides three vessels which have left the Clyde, there are six at present plying on the river, two of which carry goods as well as passengers. They have on the whole been gradually increased in tonnage as well as in the power of their engines; and still larger boats and more powerful engines are now constructing: among others one of about 100 feet keel and 17 feet beam with an engine of 24 horses' power; and one of equal burthen, having an engine of 30 horses' power. These boats are all neatly fitted up, and some of them even elegantly decorated.

"On board all the passage steam-boats are newspapers, pamphlets, books, &c. for the amusement of the passengers, and such refreshments as are desirable on so short a voyage, a distance of about 26 miles by water, and 24 by land.

"The voyage betwixt Glasgow and Greenock, including stoppages at intermediate places, is commonly accomplished in from three to four hours, the vessels taking advantage of the tide as far as circumstances will permit: but as they start at different hours from the same place, they are sometimes obliged to go part or nearly the whole of their voyage against the tide.

"The voyage has been accomplished in $2\frac{1}{4}$ hours; the tide being favourable, but against a moderate breeze of contrary wind*.

"At first, owing to the novelty and apparent danger of the conveyance, the number of passengers was so very small that the only steam-boat then on the river could hardly clear her expenses: but the degree of success which attended that attempt soon commanded public confidence. The number of passengers which now go in those boats may seem incredible to those who have not witnessed it. Travelling by land has not only been nearly superseded, but the communication very greatly increased, owing to the cheapness and facility of the conveyance. Many days, in fine weather, from 500 to 600 have gone from Glasgow to Port-Glasgow and Greenock, and returned in the same day. One of the boats alone has been known to carry 247 at one time. The increase of travelling in consequence of navigation by steam may be estimated by the number that went in the common passage-boats before the introduction of this agent: at that time, the highest estimate even for summer did not much exceed 50 up and 50 down, and those generally of the lower class of the people. The number that then went by

* The time which was allowed to the mail-coach to go between those towns was $3\frac{1}{2}$ hours, but owing to extraordinary exertion some of the coaches now run that distance in about $2\frac{1}{2}$ hours.

coaches may be thus estimated: four coaches up and four down, which might average six passengers each.

" In the summer, the pleasure of the voyage and the beauty of the scenery attract multitudes; and the bathing-places below Greenock have, in consequence of the easy passage, been crowded beyond former example."

" *General Description.*—A variety of modes of propelling steam-boats by the power of steam-engines have been projected, and many of them tried: but those on the Clyde have their machinery all constructed on one general plan; namely, that of paddle-wheels similar to under-shot water-mill wheels on each side of the vessel, which are put in motion by the steam-engine.

" Plate XXX. fig. 4. An elevation: a side view showing one of the paddle wheels.

Fig. 5. A plan, showing the extent of cabin floor.

A. The fore or second cabin.
BB. Space for the machinery.
C. The iron chimney, serving also as a mast.
D. The boiler.
EE. The steam-engine.
G. The crank.
H. The fly-wheel.
II. The paddle-wheels.
K. Ladies' cabin.
L. Steward's room.
M. Principal cabin.
NN. Stairs down to the cabins.
OO. Water closet.
PP &c. Gangway.
QQQ. Seats at stern and on the deck.
R. The rudder.
S. Covering of paddle-wheels."

One of the most ingenious kinds of steam-boats, both in its own construction and in its machinery, is that which has been recently brought into use at the *Dundee* Ferry, between the counties of Fife and Forfar, in Scotland. A very interesting account of this ferry, and the boats employed, has been published in *Jamieson's Edinburgh Journal*, by Captain Basil Hall; from this we make the following extracts.

" It will give a good idea of the importance of this ferry, to state the exact number of passengers, cattle, &c. which crossed in the year 1824.

Foot Passengers.	Carriages.	Gigs.	Cattle.	Sheep.	Horses.	Loaded Carts.
100,536	130	474	6,627	15,449	4,777	2,564

"The distance from Dundee to Newport, in a straight line, is one statute mile and a little more than a half, or very nearly 2,760 yards. At certain times of tide, the passage cannot be made directly across, owing to the mud-banks which lie nearly in the middle of the stream; so that the average distance of the passage, allowance being made for the set of the tide, may be stated at about two miles and a third. This passage is made by the twin-boat in seventeen minutes, at an average, in neap tides; and in twenty-three at spring tides. In very blowing weather, it sometimes takes from thirty to fifty minutes, and once it took an hour. During 1824, the passage was never interrupted for one whole day; and it was only five times detained throughout the whole year, owing to hard westerly gales during the ebb tide.

"There are two steam-boats belonging to the ferry, one of which is employed at a time, except in harvest, when the reapers come down, or at the seasons when numerous droves of cattle come from the north. On these occasions, both are put in requisition, though not absolutely necessary, in order to avoid the possibility of delay. In order still farther to meet the public convenience, a pinnace, with four able seamen, is stationed at each side of the ferry, for the purpose of affording a passage to travellers who are unwilling to wait for the periodical sailing of the steam-boat. These boats are also in attendance during the night, when the steam-boat has ceased to ply.

"As the twin-boat is very little known as yet in this country, an account of one may possibly prove interesting, if not useful to some readers. There are some material differences between the two boats at Dundee; but that last built being the most perfect of the two, a description of her will be the most satisactory.

"She is called the George the Fourth, is 90 feet long over all, and 29 broad; she has 6 feet 8 inches depth of hold; and draws, when light, 4½ feet of water,—and, when loaded, rarely more than 5 feet 4 inches. She is of the double kind of steam-boat, with a single paddle-wheel, working in the middle, between two divisions, or separate smaller boats, placed parallel to one another, at the distance of 8 feet apart. Over these two divisions are placed horizontal beams, covered by a deck, the planks of which, instead of being placed fore and aft, in the usual way, cross the vessel from side to side, and thereby contribute greatly to the strength of the whole. To a person standing on the deck, she appears to be but one vessel. At each end, there is a space railed off for cattle, one 33 feet by 27½, the other 27½ by 21. From 80 to 90 head of cattle is her average load; but, upon one occasion in fine weather, she actually carried 103 cattle, and 3 horses. In the middle part of

the deck, between the spaces allotted for cattle and carriages, there is ample space for foot passengers, for whom also, in rainy weather, there are two commodious cabins. The machinery of the two steam-engines (each of 20 horse power) is concealed below; but the paddle-wheel, being 14 feet in diameter, necessarily rises considerably above the deck, where it is covered by a wooden case. This wheel is 7 feet wide, and is immersed 18 inches in the water. It is a matter of perfect indifference which end of the boat goes foremost, both being alike in all respects. As the method of fixing the rudders, one of which is fixed at each end, is, of course, different from that of a ship, it may be useful to describe it particularly. The rudder is a plate of iron $4\frac{1}{2}$ feet long, and 3 feet deep. It is fastened to a vertical spindle, reaching from the middle of the stern to the water. In the first boat employed in the Tay, the rudder was attached by one end to the spindle, so that, when she was in motion, its whole length trailed behind. But this rudder being found difficult to move, a device was adopted which answers the purpose perfectly. The spindle, instead of joining the rudder at the end, is fixed to it at one-third of the length; so that, when the vessel is in motion, two-thirds are abaft, and one-third before the spindle, resembling a large weather-cock, or vane inverted. A horizontal wheel is fixed to the upper extremity of the spindle, and this is turned by a wheel and pinion by the steersman. Both the divisions composing each twin-boat are flat-bottomed, have perpendicular sides, and are sharp-bowed; the angle at which the two bows meet at the extremities being 60°, ample room is allowed for the escape of the back-water. The rudder is placed in the middle point between the two stems; and, of course, lies directly in the centre of the current of back-water thrown out by the paddle-wheel. The steersman stands on a raised platform, above the taffrail, from whence he commands a clear view over the paddle-case. There are no masts; and the only resistance which is offered to the wind is from the chimneys of the engines.

"Though the manner in which the two engines of a steam-boat are made to act in concert be known to every person at all acquainted with the subject, it may perhaps interest some readers to describe, in a popular way, the beautiful device by which this object is accomplished. The paddle-wheel is moved by one continuous shaft, to which both engines give their impulse, by means of two cranks, or bends in it, formed so as to be at right angles to each other. Thus when one of the cranks is either quite up, or quite down, and consequently the power of the engine connected with it, for the moment, entirely gone, the other crank must be in a horizontal position, and the power of its engine will be, for the same moment, at a maximum.

The result therefore is, that, precisely in proportion as one engine loses power, the other gains it; and, consequently, the united effect of the two, against the resistance, at every instant of their action, is virtually equal to the constant power of one of them at its greatest; so that, whether the engine be moving fast or slow, or the resistance great or small, the same uniform force is exerted.

"At each of the landing places, there have been built low-water piers; along the sides, or across the ends of which, the steam-boat can be placed at any time of the tide, and during all weathers; so that passengers and cattle are embarked with as much ease as if they were going along a bridge; while carriages and carts drive in on one side of the river and out again on the other, without removing the horses. The utmost attention is paid to the hours of departure. Three minutes before the town clock of Dundee strikes the hour, a bell is rung on board the boat; and the instant the hour is told, the paddle-wheel begins to move, and the vessel to glide from the pier. In like manner, when the half hour strikes at Newport, she quits the opposite pier; and so on from sun-rise to sun-set; her crossings and recrossings never being interrupted. To insure the constancy of this essential, but very difficult point, an able and active superintendent has been appointed, with a handsome salary, and a house on the spot: his exclusive business is to arrange the whole details of the passage, and to prevent all unnecessary delays. A collector also is appointed, a gentleman who, in like manner, resides constantly on the spot, and attends exclusively to the money department. In consequence of the vigilance of these two officers, acting under the judicious regulations which the trustees have from time to time established, it is most worthy of remark, that, however great the crowd of cattle, carriages, or passengers may be, not the least delay or confusion ever arises, either at the embarkation or relanding.

"On board the boat the system is equally perfect: there is a coxswain, an engineer, five seamen, and a fireman. Long practice has given to those people so exact a knowledge of the power which is in their hands, that this huge and apparently unwieldy boat is moved about with a celerity and precision altogether astonishing. To a stranger, however much accustomed he may have been to the wonders of machinery elsewhere, the effect is truly magical. The steam-boat, or, more properly, this great double raft, is discovered advancing at the rate of seven or eight miles an hour, directly for the shore, threading her course like a little skiff amongst the vessels lying in her way. In a few seconds she arrives, still at full speed, close to the shore. In the next instant she is arrested, by a touch of the engineer's hand, as suddenly as if she had struck upon a rock; and is

placed, by the sole instrumentality of her invisible machinery, close by the side of the pier, with as much accuracy as if she were in a dock, and as much gentleness as if, instead of being made of stout oak and iron, she were formed of glass. In a moment, two great folding gangways are lowered down, and her side being thus thrown open, cattle, horses, passengers, all walk out, and find themselves on land, with scarcely any circumstance having occurred to indicate they had been on the water.

"A very admirable contrivance, the invention of Messrs. J. and C. Carmichael of Dundee, has been affixed to the machinery of these twin-boats, by which all these movements are rendered extremely simple; and I am happy to have prevailed upon them to favour the world with a description of this apparatus."

It is exhibited in figs. 6, 7, 8, pl. XLIV.; and the minutiæ of the construction will be learnt from Messrs. Carmichael's account below.

"The object of the contrivance we are about to describe is to regulate the motions of the steam-vessel in a more easy manner than heretofore. By the simple motion of a small handle, or index, placed on a table upon deck, in view and in hearing of the man at the helm, and of the master of the vessel, every movement which the engine is capable of giving to the paddle-wheel may be at once commanded. The vessel may be moved forwards or backwards,—or may be retarded, or entirely stopped, at any given moment, by merely turning the handle to the places denoted by the graduations of a dial-plate. No skill is required for this purpose, so that the master himself, or a sailor under his directions, can perform the office as well as the ablest engineer. Thus, the confusion which frequently arises at night in calling out to the engineer below is avoided, and any ambiguity arising from the word of command being transmitted through several persons entirely prevented. In point of fact, it places the engine as much under command as the rudder is,—an undoubted improvement upon the clumsy method of bawling out to the engineer below, who either may not hear, or may chance to be out of the way,—circumstances which may lead to the most serious accidents.

"The different parts of the machinery are not exactly arranged in the sketch as they are executed in said boat, but we hope that the principle will be better understood from having arranged them so as they can be better seen in the sketch, Plate XLIV.

"The cylinder and jacket are cast in one piece, connected at the bottom, but altogether disconnected at the top when cast,—the vacancy between the two is closed at the top by an iron ring, and hemp or rust packing in the joints. The steam from the

boiler enters between the cylinder and jacket, by the branch A, passes round the cylinder, and communicates with the side-pipe C of the valve-chests by the branch B, but cannot enter the cylinder when the steam-valves DD are shut. The eduction-valves EE are situate below the steam-valves.

"The steam-valve rods work through a flax packing at FF, and are made hollow, to allow the eduction valve-rods to pass up the centre of them,—they are also made air-tight by a flax packing at GG.

"The valve-lifters HHHH are fast upon the lifter-rods IJ, only one of which can be properly seen; the foot of the one farthest from the eye is seen at the rocking-shaft. One of these rods lifts the upper steam-valve and lower eduction-valve; and the other the lower steam-valve and upper eduction-valve. The lower steam-valve and upper eduction-valve are represented as lifted in the sketch.

"The rocking-shaft K turns and returns upon its centre about 40°, and having two spanners (or pallets) L, projecting from it upon opposite sides, cause the lifter-rods and the valves connected with them to rise alternately.—The lifter-rods fall by their own weight, and when the pallets are horizontal, all the valves are shut, and for an instant of time are at rest.

"The rocking-shaft receives its motion from an eccentric-wheel M, fastened on the crank-shaft. The fixing of this wheel with relation to the crank and valves is a point of considerable nicety, as upon this depends the opening and shutting of the valves at the proper time.

"The eccentric-rod N, is supported on the crank-shaft by a projecting part on each side of the eccentric-wheel, turned concentric with the shaft by the brass pieces O. The four rods P, pass through these brass pieces, and slide freely in them. This part is shown in the section at Fig. 2., with part of the crank (or paddle) shaft, and the crank on one end. The other end of the eccentric-rod is supported on the roller Q; and as the crank-shaft turns round, the eccentric-rod travels backwards and forwards a distance equal to double the eccentricity of the eccentric wheel, and as the said rod is connected with the rocking-shaft by the double-ended spanner RR on one end of it, consequently the rocking-shaft will travel from one extremity of its arch of motion to the other, in the same time that the crank-shaft makes half a revolution, or in the same time that the steam-piston travels from the top to the bottom of the cylinder, or from the bottom to the top. The steam-piston is represented in the middle of the cylinder, and as the lower steam-valve and upper eduction-valve are open, the piston must be ascending, and as the crank is connected with the opposite

end of the walking-beam (or lever), the crank will be descending. By the time that the piston has reached the top, and the crank the bottom, the rocking-shaft will be in that position where the pallets upon it are horizontal, and, of course, all the valves will be shut. But the momentum of the paddle (or fly) wheel carries on the motion, and immediately the two valves that were formerly shut, viz. the upper steam-valve and lower eduction-valve, are opened, and the steam presses down the piston with a force equal to the difference between its own elasticity and the elasticity of the uncondensed vapours below the piston. Thus the engines will continue to go, and the paddle-wheel to turn in the direction of the dart.

"But that we may endeavour to explain to you the method of stopping or reversing the motion of the paddle-wheel, all that is necessary is to shut all the valves; and this is effected by disengaging the eccentric-rod from the spanner of the rocking-shaft, and the valves all shut of their own accord, by the weight of the valves, lifter rods, &c., and the engine will stand: and to set the engine agoing, either the one way or the other, is to lower the eccentric-rod, to take hold of the double-ended spanner on the end of the rocking-shaft, as represented on the sketch, and then the paddle-wheel will move in the direction of the dart, or lift the eccentric-rod to the top of the spanner on the rocking-shaft, and then the paddle-wheel will move in the opposite direction. The use of the sector formed appendages T, on the end of the eccentric-rod, is to conduct the pins on the ends of the double-ended spanner into the notches adapted for them on each side of the eccentric rod; the form of which is better seen detached, at Fig. 8.

"The hand-gearing, for starting or stopping the engines, is situated upon the deck of the boat, and all concentrated upon the top of a small table in view, and in hearing of the man at the helm, or the master, who directs both, when coming to the quay.

"1, a double-ended handle, which is upon the upright shaft 2, on the lower end of which is a bevel-wheel 3, working into another wheel 4; this wheel is on a lying shaft, which extends from the one engine to the other, and carries on each end of it a spur-pinion 5, which pinion works into the rack 6. There is a similar rack connected with the eccentric-rod of the other engine, into which the other spur-pinion works, so that, by turning the handle 1, both engines can be started, stopped, or reversed, with the greatest facility and certainty that could be wished for. These bevel-wheels, spur-pinions, and racks, must be so proportioned to one another, as that two complete turns of the handle 1 raises the eccentric-rod from the lowest to the

highest position. One turn of the handle raises or lowers the eccentric-rods into the stopping position, and one turn, either the one way or the other, as circumstances require it, sets the boat ahead or astern. There is a projecting piece 7, fixed upon the upright shaft, which catches into a notch, pressed by a spring, which supports the racks and eccentric-rods, at any of the three positions that may be required.

"As the said upright shaft makes two turns, and always stops at the same point, it is not suitable for the index. To remedy this, there is a small pinion 8, below the table, working into a wheel 9, with four times the number of teeth, for carrying the index 10. This wheel, making but half a revolution for two revolutions of the upright shaft, makes the index upon its arbour stand fore and aft when the engines are going, and thwart ships when the eccentric-rods are set in the standing position.

"The index 11 is connected with the regulating-valve 12 by rods and spanners, and turned by hand, as circumstances require.

"The index 13 is connected with the injection-cock by rods and spanners, it being always shut before the engines are stopped, and opened when the engines are started. Each engine has separate gearing for the regulating valves and injection-cocks, and graduated circles on brass plates, to show, by inspection, the position in which they are standing.

"When the engines stand for some time, it is necessary to let the steam pass freely through them for two or three seconds, on purpose to heat them, and expel any air that may have got inside. For this purpose, the long handle 14, standing by the side of the table, is fixed to a shaft 15, which goes across the front of both engines, and by four short spanners (or pallets) upon it, lifts all the valves of both engines, and allows the steam to pass freely through them by the air-pump valves. The engineer knows by the sound when to replace the handle in the position shown in the sketch; and having previously set the index for the head or stern motion in the direction wanted, and adjusted the steam-regulating index, the last thing he has got to do is to open the injection-cocks, and immediately the engines start in the direction wanted."

STEEL-YARD, an instrument used for weighing goods, &c.; the theory of which was concisely stated in art. 138 of our first volume, and succeeded by a few remarks on its conveniences and inconveniences. In addition to what was there observed, we may now state, that steel-yards, in the common purposes of commerce, have two advantages over balances. 1. That their axis of suspension is not loaded with any other

weight than that of the merchandise, the constant weight of the apparatus itself excepted; while the axis of the balance, besides the weight of the instrument, sustains a weight double to that of the merchandise. 2. The use of the balance requires a considerable assortment of weights, which cause a proportional increase in the price of the apparatus, independently of the chances of error which it multiplies, and of the time employed in producing an equilibrium. These motives induced C. Paul, inspector of weights at Geneva, to employ his thoughts on the means of so far improving steel-yards, that, either in delicate operations of the arts, or in those of the same kind which are often so necessary in the practice of physical sciences, these instruments might be substituted with advantage for common balances. In order that we may better explain in what the improvement of these steel-yards consists, it will be proper to point out what were the faults of the common ones.

1. There were none of them, in which the points of suspension were exactly in the prolongation of the line of the divisions of the beam; a circumstance which necessarily changed the relation between the arms of the lever, the power, and the resistance, according as the direction of the beam was changed from a horizontal position. We have seen steel-yards, in which a degree only of difference in the inclination of the beam produced the difference of more than a pound in the result.

2. When the shell, the beam, and weight, are made at hazard, a person who possesses a steel-yard cannot know when the instrument is deranged; and even an artist cannot repair it, but by repeated trials, and with a great loss of time.

3. The construction of the common steel-yards, which have a small and a large side, renders it necessary to invert them frequently; a laborious operation when these instruments are heavy, and which exposes the axes to the danger of damage by the effect of the shocks which that turning occasions.

As these double sides render it necessary to have a beam very straight, in order that it may be less faulty, it readily bends, which is a new source of error; and, the face which bears the numbers being narrow in proportion, it is difficult to form on it numbers sufficiently visible. These inconveniences are all avoided by the construction of C. Paul, which presents, besides, several other advantages not possessed by the old steel-yards.

1. The centres of the movement of suspension, or the two constant centres, are placed on the exact line of the divisions of the beam; an elevation almost imperceptible in the axis of the beam, destined to compensate for the very slight flexion of the bar, alone excepted.

2. The apparatus, by the construction of the beam, is balanced below its centre of motion; so that when no weight is suspended, the beam naturally remains horizontal, and resumes that position when removed from it, as also when the steel-yard is loaded and the weight is at the division, which ought to show how much the merchandise weighs. The horizontal situation in this steel-yard, as well as in the others, is known by means of the tongue, which rises vertically above the axis of suspension.

3. It may be discovered that the steel-yard is deranged, if, when not loaded, the beam does not remain horizontal.

4. The advantage of a great and a small side (which in the others augments the extent of their power of weighing) is supplied by a very simple process, which accomplishes the same end with some additional advantages. This process is to employ, on the same division, different weights. The numbers of the divisions on the bar point out the degree of heaviness expressed by the corresponding weights. For example, when the large weight of the large steel-yard weighs 18 pounds, each division it passes over on the bar is equivalent to a pound; the small weight, weighing eighteen times less than the large one, will represent, on each of these divisions, the eighteenth part of a pound or ounce; and the opposite face of the bar is marked by pounds at each eighteenth division. In this construction, therefore, we have the advantage of being able, by employing both weights at once, to ascertain, for example, almost within an ounce, the weight of 500 pounds of merchandise. It will be sufficient to add what is indicated by the small weight in ounces, to that of the large one in pounds, after an equilibrium has been obtained by the position of the two weights, viz. the large one placed at the next pound below its real weight, and the small one at the division which determines the number of ounces to be added.

5. As the beam is graduated only on one side, it may have the form of a thin bar, which renders it much less susceptible of being bent by the action of the weight, and affords room for making the figures more visible on both the faces.

6. In these steel-yards the disposition of the axes is not only such that the beam represents a mathematical lever without weight; but in the principle of its division, the interval between every two divisions is a determined and aliquot part of the distance between the two fixed points of suspension; and each of the two weights employed has for its absolute weight the unity of the weight it represents, multiplied by the number of the divisions contained in the interval between the two constant centres of motion. Thus, supposing the arms of the steel-yard

divided in such a manner that ten divisions are exactly contained in the distance between the two constant centres of motion, a weight to express the pounds on each division of the beam must really weigh ten pounds; that to point out the ounces on the same division must weigh ten ounces, &c. So that the same steel-yard may be adapted to any system of measures whatever, and in particular to the decimal system, by varying the absolute heaviness of the weights, and their relation with each other. The application of this principle will be seen hereafter in the description of the steel-yard, to which C. Paul, with great propriety, has given the name of *universal steel-yard.*

But to trace out, in a few words, the advantages of the steel-yards constructed by C. Paul for commercial purposes, we shall only observe, 1. That the buyer and seller are certain of the correctness of the instrument, if the beam remains horizontal when it is unloaded and in its usual position. 2. That these steel-yards have one suspension less than the old ones, and are so much more simple. 3. That by these means we obtain, with the greatest facility, by employing two weights, the exact weight of merchandise, with all the approximation that can be desired, and even with a greater precision than that given by common balances. There are few of these which, when loaded with 500 pounds at each end, give decided indications of an ounce variation; and the steel-yards of C. Paul possess that advantage, and cost one-half less than balances of equal dominion. 4. In the last place we may verify, every moment, the justness of the weights, by the transposition which their ratio to each other will permit; for example, by observing whether, when the weight of one pound is brought back one division, and the weight of one ounce carried forwards eighteen divisions, the equilibrium still remains.

If, instead of ascertaining the weight of the merchandise in pounds, you wished to find it according to the system of decagrammes, hectogrammes, and kilogrammes, it would be sufficient to substitute, for the ordinary weights, an assortment of three weights bearing the above names. These three weights are the decuple one of the other; and the absolute weight of that called kilogramme is to the absolute weight of that called pound, in the exact ratio of these two quantities. It may be here seen, that, by adapting to the steel-yard a system of three weights, we may arrive at the second decimal, or the centiemes of the unity of the weights employed, and even without adding or changing any thing in the division of the beam.

It is on this simple and advantageous principle that C. Paul has constructed his universal steel-yard. It serves for weighing in the usual manner, and according to any system of weights, all

ponderable bodies, to the precision of half a grain in the weight of a hundred ounces; that is to say, of a ten-thousandth part. It is employed, besides, for ascertaining the specific gravity of solids, of liquids, and even of the air itself, by processes extremely simple, and which do not require many sub-divisions in the weights.

The beam of this steel-yard when unloaded rests in equilibrio in a horizontal position. The shears are suspended by a screw to a cross horizontal bar of wood supported by two vertical pillars, which rest on the two extremities of a small wooden box furnished with three drawers, and which serves as a stand of the apparatus. This beam is divided into 200 equal parts, beginning at its centre of motion. The division is differently marked on the two faces: on the anterior face, the numbers follow each other from 10 to 200, proceeding towards the extremity; and on the other face, the numbers are marked in the opposite direction. We shall soon explain the use of this difference in the order of numeration.

A small vertical frame hangs from the cross-bar nearly at the further extremity of the steel-yard, and is destined to prevent the oscillation of the beam; it is placed at the proper height by means of the nut and screw by which it is suspended. Above the beam is a small cross-bar of brass, suspended by its two extremities from the cross-bar of wood. Different weights are hooked to it, each having marked on it its particular value. And, in the last place, a small mercurial thermometer, having the two most usual divisions, viz. Fahrenheit's and Reaumur's, and destined to point out the temperature of the air and the water during the experiments. The axis of suspension of the steel-yard rests upon two beds of very hard well-polished steel. The case is the same, but in a reversed situation, with the axis which supports the hook, that serves for suspending different parts of the apparatus, according to the purpose to which it is to be applied.

When you wish to employ it as a common steel-yard, you suspend from it a brass shell, which is an exact counterbalance for the weight of the beam when unloaded. The latter then assumes of itself a horizontal situation. You then search for the equilibrium of the substance put into this shell, by positing at the proper place, on the beam, the weight and its fractions corresponding with the system of weights adopted; and when you have found the equilibrium, you observe the weight indicated by the divisions on which each of the weights employed is found, exactly in the same manner as is done in regard to the common steel-yard.

There is also, as part of the apparatus, a glass shell suspended

occasionally in a jar filled to a certain height with water. This shell is intended for experiments relative to the specific gravity of solids. It is in equilibrium, if, when immersed into water at 20° of Reaumur, as far as the junction of the three silver wires by which it is supported, it exactly balances the weight of the beam unloaded.

When you wish, then, to try the specific gravity of a solid, you first weigh it in air; but by putting it into the brass shell, and then substituting the glass one, you weigh it in water. It is well known that the difference of these weights, employed as a divisor of the total weight in air, gives for quotient the specific gravity. Care must be taken, as in all experiments of the kind, that no bubble of air adheres to that part of the apparatus immersed in the water, or to the substance, the weight of which is required, and which is immersed also.

There is likewise a solid glass ball destined for the purpose of ascertaining the specific gravity of liquids, in the following manner:—This piece is furnished with a hook of fine gold, that it may be immersed without inconvenience in acids. When it is suspended to the hook of the steel-yard, and in the air, it is in equilibrium with the beam loaded at its extremity (either at the division marked 0 (nothing) on the backside of the beam) with weights entitled *specific*, and $\frac{1}{100}$ of specific hooked on at the other.

This ball, immersed in distilled water at 12° of Reaumur as far as the end of the straight metal wire which suspends it, is still in equilibrium, with these two weights placed in the following manner, viz. the large one at the division in the middle of the beam marked *water* on the backside of the beam, and the small one at the division 0, that is to say, the extremity. When the apparatus is thus prepared, you fill a jar with the liquid, the specific gravity of which you wish to ascertain; suspend the glass ball to the hook of the steel-yard, and immerse it into the liquid till it rises exactly above the ring from which the ball hangs, observing the temperature, and disengaging carefully all the air-bubbles that may adhere to the ball; then remove the small weight to the division 0 at the end of the beam, and convey the large one as far as that division, preceding that where the weight of the ball would raise the beam; and afterwards move the small weight as far as the division where the equilibrium will be restored, the beam being horizontal. Mark the division at which the large weight is found, and add two cyphers; to this number add the indication immediately resulting from the position of the small weight, and the sum of these two numbers gives the specific gravity of the

liquid, or its ratio with the weight of distilled water, to a ten-thousandth part.

The larger balloon is used in trying the weight of any given kind of gas compared with that of atmospheric air, in the following manner:—The weight entitled *air-tare* is arranged in such a manner that when placed in a notch, at the further extremity of the beam beyond the divisions, it forms an equilibrium with the balloon exhausted by the air-pump and suspended from the hook of the steel-yard. If the steel-yard is not then in equilibrium, it is an indication that the instrument is deranged, or that the vacuum is not perfect. The air, the relative weight of which in regard to atmospheric air you wish to ascertain, is to be introduced into the balloon, and the weight marked *air* is to be moved along the beam. The division at which it stands when an equilibrium is produced will indicate, in hundredth parts of the weight of the volume of atmospheric air that could be contained in the balloon, the weight of the gas actually inclosed in it. This indication is read about the middle of the anterior part of the beam, where the words *atmospheric air* are marked.

Not satisfied with having procured to philosophers, and those fond of accurate experiments, an instrument extremely convenient for the closet, and of very extensive use, C. Paul has endeavoured to render this apparatus portable, and has constructed various pocket steel-yards, with which the nicest experiments may be made, and the quality of gold coin be ascertained by the trial of its specific gravity. They are constructed exactly on the same principles as the Roman small steel-yard, but are necessarily less extensive in their use. They cannot be employed, for example, in determining the specific gravity of an aëriform fluid, and do not extend beyond 100 deniers of weight; but as they possess all the advantages of a balance, besides those peculiar to themselves, they are extremely convenient for philosophers who are obliged to travel.

A figure of this steel-yard and apparatus may be seen in Tilloch's Philos. Magazine, vol. iii.

A steel-yard, or balance beam, for the accurate weighing of very minute quantities, for specific gravities, &c. by Mr. J. H. *Patten*, has been recently described, as below, in the American Journal of Science.

"One great objection to the usual balance is the difficulty of getting the points of suspension of the scales to be at equal distances from the point of suspension of the beam; another is the friction—this alone is sufficient to prevent the substance to be weighed from containing an *exact* quantity of matter with

the weight used; for suppose a beam to be so nicely constructed as to turn with the tenth of a grain—now to weigh a hundred grains, that weight will be put into one dish and the substance into the other, but the tenth of a grain must be added before the scale can turn perceptibly; it therefore exceeds one hundred grains by the tenth of a grain, and the weights can only be equivalents when the index is at rest, which may be any where within the quantity required to turn the beam—sufficiently accurate for all *common* purposes, but not for weighing the gases and taking accurately specific gravities; and in analysis, where the weights are often repeated, it amounts to considerable. The only accurate method is to make the weight itself the standard; as was proposed by M. *Borda*. To do this is the object of the beam *a b c* (fig. 5. pl. XLIV.) made of steel, sufficiently strong but light. The dish is suspended at *a*, the beam itself upon an axis at *b*; at *c* is the milled head of a long screw that is fitted with a shoulder and axis, and goes through the slide *e*, that traverses upon *b c*, and carries the weight *d*. Now suppose it is wished to obtain ten grains, place that weight in the dish *f*, and screw back the weight *d* until it exactly counterbalances it. If the weight be now removed and a quantity of the substance to be weighed be substituted until the index points to where it did at first, there will then be very nearly the exact weight with but a small allowance for friction; for were this beam a common one, and so nicely constructed as to turn the 100th part of a grain, it would, by making the distance from *a* to *b* four times greater than from *b* to *d*, the point of suspension of the weight, turn with the 400th part of a grain. It is apparently an objection that 100 grains at *a* will require 400 at *d*, but the fact is settled by Coulomb, that this kind of friction does not increase in an equal proportion with the weights used; that is, if with a pound in each scale, a beam turn with one grain, if there were two pounds in each it would not require two grains.

"This beam may be used as a steel-yard by screwing the weight *d* to any number marked upon the scale, and should a greater quantity be required than that marked in the first line, another weight double of *d* may be substituted."

STEELYARDS *to ascertain animal strength*, may readily be attached to almost any kind of machinery in which animals are the first movers: and it is much to be wished that experiments were frequently made with them, in order that our knowledge on this point might be increased.

The following contrivance, falling under this head, has been lately proposed for determining the power of horses drawing in mills. Let AB (fig. 10. pl. XXXII.) be the vertical shaft to

which the horizontal horse-poles AC, AD, are attached. Let one horse work the machine by drawing at the ear E; but instead of the transverse splinter-bar, to which the harness is fixed, being simply hung upon the hook *h*, let a good spring steel-yard be interposed between that cross-bar and the hook, the graduations of which shall, when the machinery is put into motion, indicate the resistance (in lbs.) overcome by the animal, including the weight of the mass moved, the friction, &c. Near the extremity of the opposite horse-pole AD, let there be fixed a strong and correct common steel-yard, whose divisions shall show the various weights from 40 or 50 to 200 lbs. and whose centre of motion shall be at the point *f* on the fixed stand. Let the cord *c*, which is fastened to the shorter arm of this steel-yard, pass (with as little friction as possible) over the pulley *p*, and thus, being turned into the horizontal direction, or rather inclining a little upwards, let it be fixed to the cross-bar of the harness of a second horse, equal in point of strength to the former. Then, if the two horses thus attached to the ears E and F be made to pass over the walk in the same direction, following each other constantly at the distance of a semi-circumference; while that which draws at the ear E overcomes the whole pressure and resistance opposed by the work, the other which draws at F by the cord over the pulley *p*, will raise the weight *w* of the steel-yard; which, therefore, by being moved to and fro upon the arm *fi*, may be brought to exhibit an exact counterpoise, or measure of the exertion and power of the horse. And in order to ensure the greatest degree of accuracy in this respect, the motion of the two animals and the position of the weight *w* should be so adjusted, that the same weight should be shown by the graduations both of the spring and of the lever steel-yard. The shaking of the machinery will in some measure disturb the effect: but an ingenious manager of the experiments will find means of checking this: and as to the centrifugal force to which the weight *w* is exposed, it will never be of material consequence in any of the slow motions which will be produced by this kind of work.

Each experiment should occupy the place of a fair day's work for the horses; for the conclusions deduced from shorter and irregular efforts are always erroneous in excess, and should be guarded against. The rate at which the animals move may readily be ascertained from the known circumference of the walk, and the number of rounds they are observed to make in ten or fifteen minutes.

A slight modification will adapt this contrivance to the determination of the power of men pushing at the bars of a capstan; to this end it will only be necessary to have a sufficiently strong

frame in form of a T, one end of which may be fastened to a noose in the cord passing round the pulley *p*, while a man pushes at the transverse bar of the frame, with the same energy as he would employ at the capstan bar.

By means of such steel-yards properly applied to waggons, &c. upon tolerably smooth roads, and two horses marching abreast (one drawing the load, the other raising the weight), experiments might be instituted to ascertain the magnitude of the efforts of horses when drawing in rectilinear paths.

In Desaguliers's Experimental Philosophy, vol. I. some steel-yards are described, by which the strength of men may be ascertained when standing still, and pulling or pushing upwards or downwards: we had, at first, proposed to describe them in this place; but as all these contrivances are nearly on the same principle, and may easily be adapted to any particular purpose, we omit the minute descriptions and drawings, as well as of *dynamometers*, to make room for other subjects.

STREAM-MEASURERS, are instruments by which the velocity of currents of water in rivers, mill-ponds, &c. may be determined.

In the introductory part of this volume, we spoke of the common and gross methods of ascertaining the velocity of running water in canals, &c. But as more scientific and accurate methods have been devised, it seems proper to insert the best of them with which we are acquainted, in this place.

1. M. *Pitot* invented a stream measurer of a simple construction, by means of which the velocity of any part of a stream may readily be found. This instrument is composed of two long tubes of glass open at both ends; one of these tubes is cylindrical throughout; the other has one of its extremities bent into nearly a right angle, and gradually enlarges like a funnel, or the mouth of a trumpet: these tubes are both fixed in grooves in a triangular prism of wood; so that their lower extremities are both on the same level, standing thus one by the side of the other, and tolerably well preserved from accidents. The frame in which these tubes stand is graduated, close by the side of them, into divisions of inches and lines.

To use this instrument, plunge it perpendicularly into the water, in such manner that the opening of the funnel at the bottom of one of the tubes shall be completely opposed to the direction of the current, and the water pass freely through the funnel up into the tube. Then observe to what height the water rises in each tube, and note the difference of altitudes; for this difference will be the height due to the velocity of the stream. It is manifest, that the water in the cylindrical tube will be raised to the same height as the surface of the stream,

by the hydrostatic pressure: while the water entering from the current by the funnel into the other tube, will be compelled to rise above that surface by a space at which it will be sustained by the impulse of the moving fluid: that is, the momentum of the stream will be in equilibrio with the column of water sustained in one tube above the surface of that in the other. In estimating the velocity by means of this instrument, we must have recourse to the theory in art. 439, &c. vol. I. as corrected by the experiments in art. 460. Thus, if h, the height of the column sustained by the stream, or the difference of heights in the two tubes, be in feet, we shall have $v = 6\cdot5 \sqrt{h}$, nearly, the velocity, per second, of the stream; if h be in inches, then $v = 22\cdot47 \sqrt{h}$, nearly.

It will be easy to put the funnel into the most rapid part of the stream, if it be moved about to different places until the difference of altitude in the two tubes becomes the greatest. In some cases it will happen, that the immersion of the instrument will produce a little eddy in the water, and thus disturb the accuracy of the observation; but keeping the instrument immersed only a few seconds will correct this. The wind would also affect the accuracy of the experiments; it is, therefore, advisable to make them when there is little or no wind. By means of this instrument a great number of curious and useful observations may easily be made: the velocity of water at various depths in a canal or river may be found with tolerable accuracy, and a mean of the whole drawn, or they may be applied to the correcting of the theory of waters running down gentle slopes. The observations may likewise be applied to ascertain whether the augmentations of the velocities are in proportion to the increase of water passing along the same canal, or what other relation subsists between them, &c.

Where great accuracy is not required, the tube, with the funnel at bottom, will alone be sufficient; as the surface of the water will be indicated with tolerable precision, by that part of the prismatic frame for the tube which has been moistened by the immersion.

M. Pitot likewise proposed that a similar instrument should be used instead of a log to determine the rate at which a ship sails. For this purpose, place in the middle of the vessel, or as near as can be at the centre of its oscillations, two tubes of metal of three or four lines in diameter, one of them being straight, the other bent at bottom, and enlarged into a conical funnel; the bottoms of both are to dip into the water of the sea in which the vessel sails, and there will be no evil to apprehend from orifices so minute: into these metallic tubes are closely fitted two others of a convenient height for the observa-

tions. The water will rise in the first of these tubes up to its level on the outside of the ship; and in the second up to a certain height, which will indicate, as above, the velocity of the vessel: for the funnel being turned towards the prow of the ship, it will, in consequence of the motion, be affected in like manner, as if it were plunged into the stream of a running water; and thus the velocity of the vessel is found by the same theorem as that of the current. This method has lately been re-proposed in this country, without any acknowledgments to M. Pitot. We do not, however, recommend its adoption aboard a ship; for, notwithstanding its theoretical ingenuity, it is liable to many sources of error in the practice, and would not, it is probable, furnish more accurate measures of a ship's way than those deduced from the log.

2. Another good and simple method of measuring the velocity of water in a canal, river, &c. is that described by the Abbé *Mann*, in his Treatise on Rivers, Philosophical Transactions, vol. 69. It is this:—Take a cylindrical piece of dry light wood, and of a length something less than the depth of the water in the river; about one end of it let there be suspended as many small weights as may keep the cylinder in a vertical or upright position, with its head just above water. To the centre of this end fix a small straight rod, precisely in the direction of the cylinder's axis: to the end that, when the instrument is suspended in the water, the deviations of the rod from a perpendicularity to the surface of it may indicate which end of the cylinder goes foremost, by which may be discovered the different velocities of the water at different depths; for when the rod inclines forward, according to the direction of the current, it is a proof that the surface of the water has the greatest velocity; but when it reclines backward, it shows that the swiftest current is at the bottom; and when it remains perpendicular, it is a sign that the velocities at the top and bottom are equal.

This instrument, being placed in the current of a river or canal, receives all the percussions of the water throughout the whole depth, and will have an equal velocity with that of the whole current from the surface to the bottom at the place where it is put in; and by that means may be found, both with exactness and ease, the mean velocity of that part of the river for any determinate distance and time.

But to obtain the mean velocity of the whole section of the river, the instrument must be put successively both in the middle and towards the sides, because the velocities at those places are often very different from each other. Having by this means found the several velocities, from the spaces run

over in certain times, the arithmetical mean proportional of all these trials, which is found by dividing the common sum of them all by the number of the trials, will be the mean velocity of the river or canal. And if this medium velocity be multiplied by the area of the transverse section of the waters at any place, the product will be the quantity running through that place in a second of time.

If it be required to find the velocity of the current only at the surface, or at the middle, or at the bottom, a sphere of wood loaded, or a common bottle corked with a little water in it, of such a weight as will remain suspended in equilibrio with the water at the surface or depth which we want to measure, will be better for the purpose than the cylinder, because it is only affected by the water of that sole part of the current where it remains suspended.

Both the cylinder and the globe may be easily guided into that part which we want to measure, by means of two threads or small cords, which two persons, one on each side of the canal or river, must hold and direct; taking care at the same time neither to retard nor accelerate the motion of the instrument. For other contrivances for this purpose, as well as for a table of the relations of velocity at the surface, bottoms, &c. of a stream or river, see *Du Buat, Hydraulique*, tom. I. and *Gregory's Mathematics for Practical Men*, pp 300, 312.

SURFACE-PLANING *Machinery.* In October, 1802, a patent was taken out by the late Mr. Joseph Bramah for machinery for the purpose of producing straight, smooth, parallel surfaces, and curvilinear surfaces, on wood, and other materials requiring accuracy, in a manner much more expeditious and perfect than can be performed by the use of axes, saws, planes, and other cutting instruments, used *by hand.* As many particulars in the specification of this patent are highly curious, and cannot fail to be very beneficial, we shall extract the greater part of it from the Repertory of Arts and Manufactures, vol. ii. N. S.

"The principal parts of my invention are as follows; that is to say, to shorten and reduce manual labour, and the consequent expenses which attend it, by producing the effects stated in my patent by the use of machinery, which may be worked by animal, elementary, or manual force; and which said effects are to produce straight, true, smooth, and parallel surfaces, in the preparation of all the component parts of work consisting of wood, ivory, horn, stone, metals, or any other sort of materials, or composition usually prepared, and render it (*them*) true and fit for use, by means of edge-tools of every description. I do not rest the merits of this my said invention on any novelty

in the general principle of the machinery I employ, because the public benefit I propose will rather depend on new effects, produced by a new application of principles already known, and machinery already in use for other purposes, in various branches of British manufacture. This machinery, and the new manner of using it, with some improvements in the construction, together with sundry tools and appendages never in use before, are particularly described and explained hereunder.

"I mean to use and apply for the purposes above stated every kind of edge-tool, or cutter, already known, either in their present shape, or with such variations and improvements as the variety of operations I may encounter may severally call for. But the tools, instead of being applied by hand, as usual, I fix, as judgment may direct, on frames drove (*driven*) by machinery: some of which frames I move in a rotatory direction round an upright shaft; and others having their shaft lying in a horizontal position, like a common lathe for turning wood, &c. In other instances I fix these tools, cutters, &c. on frames which slide in stationed grooves, or otherwise, and like the former calculated for connexion with, and to be driven by, machinery, all of which are hereafter further explained and particularized.

"The principal points on which the merits of the invention rest are the following. First, I cause the materials meant to be wrought true and perfect, as above described, to slide into contact with the tool, instead of the tool being carried by the hand over the work, in the usual way.

"Secondly, I make the tool, of whatsoever cutting kind it be, to traverse across the work in a square or oblique direction; except in some cases, where it may be necessary to fix the tool or cutter in an immoveable station, and cause the work to fall in contact with it by a motion, confining it so to do, similar to the operations performed on a drawing-bench.

"Thirdly, in some cases I use, instead of common saws, axes, planes, chisels, and other such instruments, usually applied by hand; cutters, knives, shaves, planes, and the like, variously, as the nature of the work may render necessary; some in form of bent knives, spoke-shaves, or deep-cutting gouges, similar to those used by turners for cutting off the roughest part. I also apply planes of various shapes and construction, as the work may require, to follow the former in succession, under the same operation; and which latter I call furnishers.

"Fourthly, these cutters, knives, &c. I fix on frames of wood, or metal, properly contrived for their reception, and from which they maybe easily detached for the purpose of sharpening, and the like—these I call cutter-frames. These cutter-frames I

move in cases like those on which the saws are fixed in a sawing-mill, and sometimes to reciprocate in a horizontal direction, confined and stationed, by grooves or otherwise, as may be found best calculated to answer the several works intended. In other instances, and which I apprehend will generally have the preference, I fix cutter-frames on a rotatory upright shaft, turning on a step, and carrying the frame round in a direction similar to the upper mill-stone; and sometimes I cause the frames to turn on a horizontal shaft, just resembling the mandrel of a common turning-lathe, or those machines used for cutting logwood, &c. for the dyers' uses. When these frames are mounted in any of the foregoing directions for cutting, planes, &c. are fixed so as to fall successionally *(successively)* in contact with the wood or other materials to be cut, so that the cutter or tool calculated to take the rough and hilly part operates the first, and those that follow must be so regulated as to reduce the material down to the line intended for the surface. These cutter-frames must also have the property of being regulated by a screw or otherwise, so as to approach nearer the work, or recede at pleasure, in order that a deeper or shallower cut may be taken at discretion, or that the machine may repeat its action without raising or depressing the materials on which they act. The manner of thus regulating the cutter-frames, when on an upright shaft, is particularly described below. These cutter-frames may be made of any magnitude and dimensions the work requires, only observing to make the diameter of those on the rotatory plane so as to exceed twice the width of the materials to be cut, as the said materials must slide so as to pass the shaft on which the cutter-frame revolves, when on the upright principle.

"Fifthly, when I use upright shafts, for the purpose of carrying the cutter-frame as above described, I do not mean that the lower end or point of such shafts shall come in contact with, or rest on, the bottom of the step or box in which they stand; neither do I mean that such said shafts shall rest or turn on any stationed unalterable point at rest, but the pivot or lower point of the shaft shall actually rest and turn on a fluid body, such as oil, or any other fluid proper for that purpose, a considerable portion of which is always to be kept between the lower point of the shaft and the bottom of the step in which it works. The said shafts may be either raised or depressed at pleasure to any required altitude, by means of a greater or less quantity of the said fluid being confined as aforesaid, between the end of the shaft and the bottom of the step. This device * I deem of great

* See Count de Thiville's specification, published in the fourteenth volume of th first series of the Repertory, or the English Encyclopædia, art. WATERWORKS, fo the development of a similar invention.

consequence in the fabrication of all kinds of machinery, where massy and heavy loaded upright shafts are used; and I perform it in the following manner; that is to say: The lower part of the shaft must be turned perfectly smooth and cylindrical, to a height something above the greatest distance or length the shaft will ever be required to be raised or depressed when in use. This part of the shaft I immerse or drop into a hollow cylinder, which fits its circumference near enough to allow freedom of motion, but sufficiently fitted to prevent shake. This cylinder I call the step-cylinder, and *(which)* must be of a length nearly equal to that of the cylindrical part of the shaft above mentioned, so that when the point of the shaft rests on the bottom of the cylinder, the parallel or cylindrical part may be something above the top or upper end of the step-cylinder. In the upper end of this step-cylinder I make a stuffing-box, by means of a double-cupped leather, or other materials, surrounding the cylindrical part of the shaft in such a way as will cause the junction, when the shaft is passed through it, to remain water-tight under any pressure that may be felt from the efforts of the fluid retained as before mentioned, to make its escape upwards through this part, *(which)* I have called the stuffing-box, when the shaft, with all its load, is passed through it, and immersed in the cylinder below. When this is done, the injecting-pipe of a small forcing-pump, similar to those I use in my patent press, must form a junction with the step cylinder in some part below the stuffing-box; then the pump being worked, the oil, or other fluid injected by it, will, by pressing in all directions, cause the shaft to be raised from its rest, on the bottom of the cylinder, and to be slided up through the stuffing-box just the same as the piston of my patent press; and by this means the shaft, with all its incumbrance, and whatever may be its weight, may be raised to any given point at pleasure, and at the same time it will be left resting on the fluid under it, whatever the quantity or thickness of such fluid may be between its points and the bottom of the step-cylinder. By this means the shaft, with all its incumbent load, as aforesaid, should it even amount to hundreds or thousands of tons, can be easily raised and depressed to any required point at pleasure, by the alternate injunction *(injection)* or discharge of the fluid used, exactly the same as performed by my patent press as aforesaid; and at the same time all friction will be avoided, except that of the stuffing-box, which will be comparatively trifling to that which would result from the resting of such a shaft on the bottom of the step, in the usual way. Thus will be gained the properties above stated; and in addition thereto, I think it may be inferred, that, provided the stuffing-box is kept perfectly fluid tight, such a

shaft, thus buoyed up by and turning in a proper fluid, may continue working for years, or perhaps hundreds of years, without a fresh supply of oil, or whatever other fluid substance is found the most proper to apply.

"Sixthly, the material that is to be cut and made true must be firmly fixed on a platform, or frame, made to slide with perfect truth, either on wheels or in grooves, &c similar to those frames in a saw-mill on which the timber is carried to the saws. These frames must be moved in a steady progressive manner, as the cutter-frame turns round, either by the same power which moves the latter, or otherwise, as may be found to answer best in practice. This motion also must be under the power of a regulator; so that the motion of the sliding-frame may be properly adjusted according to the nature of the work. The motion of the cutter frames must also be under the control of a regulator; so that the velocity of the tool in passing over the work may be made quicker or slower, as such work may respectively require, to cause the cutter to act properly, and to the best advantage.

"Seventhly, I regulate the motions of both these parts of the apparatus, as aforementioned, by means of a new invention, which I call a universal regulator of velocity, and which is composed as follows: viz. I take any number of cog-wheels, of different diameters, with teeth, that will exactly fit each other through the whole, suppose ten, or any other number, but for example say ten, the smallest of which shall not exceed one inch in diameter, and the largest suppose ten inches in diameter, and all the rest to mount by regular gradations in their diameters from one to ten. I fix these ten wheels fast and immoveable, on an axis perfectly true, so as to form a cone of wheels. I then take ten other wheels, exactly the same in all respects as the former, and fix them on another axis, also perfectly true, and the wheels in conical gradation also; but these latter wheels I do not fix fast on their axis, like the former, but leave them all loose so as to turn upon the said axis, contrary to the former, which are fixed. All these latter wheels I have the power of locking by a pin, or otherwise, so that I can at discretion lock or set fast any single wheel at pleasure. I then place the two axises *(axes)* parallel to each other, with the wheels which form the two cones, as above described, in reverse position, so that the large wheel at the one end of the cone may lock its teeth into the smallest one in the cone opposite, and likewise *vice versa*. Then suppose the axis on which the wheels are permanently fixed to be turned about, all the wheels on the other axis will be carried round with an equal velocity with the former, but their axis will not move. Then

lock the largest wheel on the loose axis, and by turning about the fast *(fastened)* axis as before, it must make ten revolutions while the opposite performs but one: then by unlocking the largest wheel and locking the smallest one at the contrary end of the cone in its stead, and turning as before, the fast *(fastened)* axis will then turn the opposite ten times while itself only revolves once. Thus the axes, or shafts, of these cones, or conical combination of wheels, may turn each other reciprocally, as one to ten, and as ten to one; which collectively produces a change in velocity under a uniform action of the *primum mobile*, as ten to a hundred: for when the small wheel on the loose axis is locked, and the fast one makes ten revolutions, the former will have one hundred. And by adding to the number of those wheels and extending the cones, which may be done *ad infinitum*, velocity may be likewise infinitely varied by this simple contrivance—A may turn B with a speed equal to thousands or millions of times its own motion; and by changing a pin and locking a different wheel, as above described, B will turn A in the same proportion, and their power will *(be) transferred to each, in proportion as their velocities, reciprocally.* Here is then a universal regulator at once for both power and velocity. In some instances I produce a like effect by the same necessary number of wheels, made to correspond in conical order, but instead of being all constantly mounted on the axises *(axes)* or shafts, as above described, they will reciprocally *(be)* changed from one axis to the other in single pairs, match according to the speed or power wanted, just as in the former instance. This method will have in all respects the same effect, but is not so convenient as when the wheels are all fixed, &c.

"Eighthly, when spherical surfaces are to be produced perfectly true, and parallel to *(equidistant from)* their centres in all directions, I use a tool, or cutter, of a proper shape, according to the nature of the materials to be cut. This tool must be fixed on a cutter-frame, fastened to the rest of any common lathe, so as to present its point exactly to a line drawn through the centre of the mandrel of the lathe horizontally, and the said frame on which the cutter is fixed must have the capacity of drawing out, at pleasure, to any required distance, to accommodate the diameter of the sphere to be cut or turned true. This cutter-frame must be likewise made to turn upon a centre or pin, very firm, and steadily fixed on the rest above mentioned, so as to enable the cutter to be turned by its frame round a centre exactly perpendicular to the centre of the lathe or line before mentioned, by which the altitude of the tool's point is to be regulated; when this is done, and the wood or

other materials fixed on the lathe in the usual way, the cutter-frame must be drawn nearer, or farther distant from the centre on which it turns, to accommodate the diameter, just the same as the common rest. If the materials be rough, and require to be reduced to a spherical form by gradations, the work may be repeatedly gone over by the cutter, before it reaches the diameter proposed. By this simple apparatus the difficulty of turning perfect spheres is overcome; as it must be obvious to any person of the most ordinary capacity in mechanics, that while the work is turning in the lathe in a vertical direction, and the tool or cutter is by the hand, or otherwise, turned, at the same time, in a perfectly horizontal direction, round a centre, opposite to the actual centre of the sphere, the point of the tool or cutter must, of necessity, generate or turn a perfect sphere, true in all directions, without the smallest attention or assistance from the use of the instrument. I mention here the application of the cutter-frame to a common lathe, conceiving it will, by such an explanation, be more familiarly understood without a drawing; but, by this method, spheres of any practical magnitude may be cut with perfect ease and certainty.

"Ninthly, when concave surfaces are to be produced perfectly true, smooth, and parallel to *(equidistant from)* their respective spherical centres, the work is fixed on a machine the same in all respects as the common turning lathe, as in the instance last referred to: I then fix a tool or cutter on a centre, exactly in a line, both perpendicular to, and on a level with, the exact centre of the shaft or mandrel on which the work revolves: and which cutter or tool projects to the required radial distance with its point, so that when the work goes round by the revolution of the lathe, the tool or cutter at the same time revolving round its centre, a spherical concave will be generated and produced by the fluction* of its point, as in the instance of the convex sphere.

"Tenthly, I convert solid wood, or other materials, into a thin concave shell, similar to a dish; I cut them alternately out of each other, beginning at the smallest, by means of another tool or cutter, likewise moving on a stationed centre, as before, exactly on a level with, and perpendicularly true with the centre of the mandrel or shaft of the machine on which the work is fixed. This tool, or cutter, is made at its exterior point, or cutting end, of such a shape as best suits the nature of the work: and its shank or stem is bent to the exact circle the concave is meant to be: it is then fixed on an arm or frame calculated to

* Compared with the record.

receive others of different circles, according to the work; in fact the same frame may be used which is above described to hold the tool for cutting spheres, either of the concave or convex kind. The tool must be fixed on this frame or arm, as above mentioned, at such a radial distance from the centre on which the frame or arm turns, so as to form a quadrant with one leg, turning on its centre, and the tool forming the periphery with its cutting point projecting to the line of the deficient leg. Before this tool begins its action, a common rest must be applied close to the face of the work, in order to support the tool when it begins its cut; and on which rest the tool will slide till its point proceeds under the control of the centre on which its frame is fixed, until it reaches the horizontal line of the lathe's centre, when the part cut off, or the inner dish, will fall from the stock, and leave the rest for the operation of another tool, of a larger circle. Thus the operation may be repeated till the whole lump is converted according to the intentions of the owner."

Mechanism upon the principle of this specification, for planing, has been erected and employed to a very great extent in the carriage department of the Royal Arsenal, Woolwich.

SYPHON, with Close's and Venturi's new applications of it to convey water *above* the level of the reservoir. See CRANE.

TEETH OF WHEELS, and LEAVES *of pinions*, require great care and judgment in their formation, that they may neither clog the machinery with unnecessary friction, nor act so irregularly as to produce any inequalities in the motion, and a consequent wearing away of one part before another is much affected by the work.

Several eminent mathematicians upon the continent, and a few in England and Scotland, have directed their investigations towards a subject so essential to the perfection of machinery; yet, although Roemer, Varignon, De la Hire, Camus, Euler, Emerson, Kaestner, and Robison, have turned their thoughts to this object, and some of them have struck out rules of ready application in practice, it is to be regretted that these rules have been little followed by practical mechanics, most of whom have in this case been more inclined to follow a set of hackneyed rules handed down from one workman to another, though completely destitute of scientific principle. Even watchmakers, in whose constructions a little more than common skill and nicety in the execution might be expected, are but few of them acquainted with any rules founded upon the deductions of accurate theory; but commonly, we are informed, give to their teeth the shape assumed by a horse-hair when held bent between the fingers; a

method so vague that it is difficult to conceive how it came to be adopted.

The best, most accurate, and at the same time simple rules, for the formation of teeth and pinions, with which we are acquainted, have been given by M. Camus, in the third part of his *Cours de Mathematique*, and by Dr. Brewster, among his judicious additions to *Ferguson's Lectures*. As Ferguson's work, with Dr. Brewster's improvements, may be beneficially consulted by every practical mechanic, we would refer those to it who wish to peruse his ingenious dissertation; and shall in this place extract some of the useful rules of Camus, translating, with occasional alterations and additions, from the edition of 1759.

The best form that can be given to the teeth of any machine is, in general, that which will cause those teeth to act upon each other in an equally favourable manner, or which will enable a constant power to communicate a uniform motion. Now, if all wheels could have their teeth infinitely small, as if two wheels should have their rims surrounded with buff leather whose protuberances may be considered as teeth, and then made to act on each other (see the article WHEEL), their engagement might be regarded as simple contact, and would possess the desired property; since the wheels would in that case have both the same tangential force. The finite and sensible teeth made in wheels and pinions, and acting upon one another in the same plane, will therefore be such as are required when the wheel moves the pinion, or the pinion the wheel, just as though they simply touched each other.

It must be premised that the distance from the centre of a wheel or a pinion to the extremity of any one of its teeth or leaves, is called the *true radius* of such wheel or pinion; and, when a wheel and pinion are properly fixed and adjusted for mutual action upon each other, the line drawn from one centre to the other is called *the line of the centres*, while the portions of this line into which it is divided in the respective ratio of the number of teeth in the wheel and pinion, are denominated the *primitive radii* of such wheel and pinion. Now it is demonstrated by Camus, that the wheel and pinion will have the same force for turning at their primitive circumferences, when the right line drawn from the point of contact of two teeth perpendicular to their curvature, passes through the point which separates the primitive radii of the wheel and pinion. Hence, we must regard as the best figures which can be given to the teeth of wheels and pinions, those which so act with respect to each other, that the line perpendicular to the parts which touch

will always pass through the same point where the primitive radii of the wheel and pinion terminate in the line of the centres. This condition, it is well known to mathematicians, may be secured by making the faces of the teeth epicycloidal, and of magnitudes regulated by those of the wheels and the number of the teeth.

To convey a familiar idea of the nature of epicycloids to such readers as are not very conversant in mathematics, suggesting, at the same time, an eligible method of describing them, a definition is here given.

Let there be any two circles CAR, AHX, (fig. 14. pl. XXXII.) formed of wood, or brass, or other metal, placed upon a table or upon a flat metallic plate so as to touch each other, as in C: then if the circle AHX be made to revolve with its circumference always in contact with the circumference of the circle CAR, a style, or tracing pin, or projecting point, fixed upon the circumference of the revolving circle, will, during its motion, trace upon the table or plate below the two circles a curve which is called an *epicycloid*. The circle which in revolving describes an epicycloid, by a point in its circumference, is called the *generating circle*, and the arc of the immoveable circle, which is equal to the circumference of the revolving circle, and every point of which is touched in succession by the several points of the revolving circumference, is called the *base* of the epicycloid. When the generating circle revolves without the immoveable circle, the epicycloid is called an *exterior epicycloid*; but if the generating circle revolves within the other circle, the epicycloid is called *interior*: it is the former to which most persons have confined their attention in discussions relative to the teeth of wheels. Epicycloidal arcs may manifestly be described merely by means of segments of circles of a due magnitude; and little patterns of pasteboard, or of brass, may easily be cut to coincide with such arcs, so as to form what the workmen call *templets* or pattern teeth, to regulate the shape of those actually to be constructed on a wheel or pinion.

When three circles CAR, AHX, ABY, touch continually in one point, there will be generated an exterior and an interior epicycloid at the same time: and in this case when the circle ABY has its diameter half that of AHX, the interior epicycloid HE which touches the exterior CE, will be a right line always directed to the centre B, of the circle AHX. Hence it follows that when two circles, as CAR, AHX, touch each other continually, and the one compels the other to revolve, carrying it along by the point of contact A, if we conceive a radius BH, in the circle AHX, and after making arc AC = arc AH, describe through the point C, taken as the origin, an exterior epicycloid

CE, which has for its generating circle one whose diameter is equal to the radius BH, such radius BH will, during the motion of the two circles CAR, AHX, always touch the epicycloid CE, in the point E, where this epicycloid is cut by the right line AE, perpendicular to its curvature. Thus, instead of conceiving that one of these two circles moves the other by the point of contact A, we may cause the radius BH of the circle AHX to be impelled by an epicycloid CE, attached to the circle CAR, and described by the motion of the circle AEY, whose diameter is equal to the radius BH: we may also, reciprocally, cause the epicycloid CE attached to the circle R, to be impelled by the radius BH of the other circle; and so, by means of the epicycloid CE and the radius BH, or a series of such epicycloids and such radii properly disposed, the two circles might move each other as though they were impelled by the point of contact A. The best form of teeth of wheels and pinions, when one of these is to be a right line, may readily be deduced from this consideration.

If there were only two circles touching one another in the point A, and if the motion of the one were communicated to the other by the point of contact, any point whatever, E of the circumference AEY (fig. 14. pl. XXXII.) would describe on the moveable plane of the circle CAR, an epicycloid CE; and this epicycloid, when supposed to be attached to the circle CAR, would move the circle AEY, impelling it by the point E of its circumference, in the same manner as the former circle would move the latter, communicating motion to it by the point of contact A; and, reciprocally, the point E of the circumference of the circle AEY turning upon its centre G, would cause the circle CAR to revolve, impelling it by the epicycloid CE, supposed to be attached to this circle CAR; in the same manner that the same circle AEY would move the circle CAR, by communicating its motion through the point of contact A. And hence may be deduced the best shape for the teeth of a wheel, when it is to drive, instead of a toothed pinion, a lantern composed of spindles.

Since it is rather simpler to shape the teeth of a wheel to engage with the spindles of a lantern, than those which are to act with the leaves of a pinion; we shall first consider that case, and, supposing the number of teeth of a wheel, and of spindles of a lantern, together with the distance of their centres, to be given, shall show how to determine the primitive and true radius of the wheel, the magnitude and shape of the teeth, and the depth of their engagement in the lantern.

Here we must commence with supposing the spindles of the lantern to be indefinitely thin, such as may be represented on

any plane section of the lantern, by mere central points. Let, then, the number of teeth in the wheel be denoted by m (suppose 30) and the number of spindles in the lantern by n (suppose 8), and let GF be the line of the centres (fig. 5. pl. XXXI.) the letter F being referred to the point of concourse of the converging lines from A, D, X, R, whose continuations are omitted in the figure, to save room upon the plate. Divide the whole line GF into two parts, in the ratio of m to n, that is, make $AF = \frac{m}{m+n} FG$, and $AG = \frac{n}{m+n} FG$, so will AF and AG be the required primitive radii of the wheel and lantern. With the primitive radius of the lantern describe the circle AEHIh, and divide its circumference into n (8) equal parts, marking the points of division A, E, H, I, K, &c. for the positions of the assumed indefinitely thin spindles: also, describe with the primitive radius of the wheel the circumference CSTN, and divide it into m (30) equal parts, one of which is CA; and let AL be the small vacuity or interval which it is thought proper to leave between the teeth of the wheel, for the play of the engagement. Then CL will be the foot of one tooth, through the extremities of which describe two opposite epicycloids CEP and LMP, which turn their convexities towards the neighbouring teeth, and which have the circle CAN for base, and EHKh for generating circle. And proceed in a similar manner to describe the other teeth, as AQN, &c. From this construction it is obvious that the distance from F, the centre of the wheel, to P, the point concourse of the two epicycloids, forming a tooth, is the greatest true radius that the wheel can have, in the proposed case; and since no more of any tooth is wanted than what reaches from C to E, the preceding spindle, when the bottom L, of the tooth, comes in contact with the next spindle A, the whole quantity EPM may be cut away from the tooth, and it will still continue effectual in the machinery; so that the distance from E, to the centre F, is the shortest radius which the wheel can have, and any radius may be adopted between the limits FE and FP.

Our next business is to reform all these teeth, to make them accord with the spindles of a finite diameter, which the wheel must have. Here, if the radius of the spindles, which we suppose equal, be given, describe with this radius, on the plane of each tooth, as many small arcs as can well be done, having all their centres in the two epicycloids which form the tooth; and trace out two curves, such as RO, SO, through all these arcs parallel to the epicycloids, between which the first teeth are contained. These new curves RO, SO, or TY, VY, being thus described, will reform the first teeth CPL, AQN, &c. and will

comprehend between them and the primitive circle of the wheel, the spaces ROS, TYV, &c. which will be the proper figures of the teeth of the wheel, to drive the spindles A, E, H, F, K, *i*, *h*, *e*, the diameters of which are given. For, if we imagine that the centre E of a spindle is moved by the tooth CPL, the curve RO which is parallel to the epicycloid CP, and is distant from the radius of the spindle E, will always touch the circumference of that spindle; hence the curve RO will move the cylindric spindle, just as the tooth CPL, formed by two epicycloidal portions, would move the axis E of that spindle; consequently, the tooth ROS has the proper form to move a lantern with the proposed cylindric spindles.

When the common radius of the spindles of the lantern is not given, if it be necessary to correct the first teeth of the wheel CPL, AQN, so that the new teeth shall leave between them vacuities equal to the breadth of their feet; and if it be proposed, likewise, that the play of the engagement should always be equal to AL; then divide into two equal parts CD and DL the foot of the tooth CL, and having taken on both sides of the point D, two parts DR and DS, equal to $\frac{1}{4}$ of the arc AC, the arc RS will be the foot of the new tooth demanded. Then, with a radius equal to the chord of the arc CR, trace out the circles A, E, H, &c. which will represent the magnitude of the spindles of the lantern. Lastly, to complete the correction of the first teeth of the wheel, describe with the same radius, on the plane of them, as many small arcs as may be, having their centres in the epicycloids which comprise the first teeth: and if there be drawn curves through all these small arcs, such as RO and SO, or TY and VY, we shall have new teeth ROS, and TVY, which will leave vacuities between them equal to the breadth of their feet; which will have the play demanded, while acting in each other, and which will drive the spindles whose size has been determined, in like manner as the former teeth would have driven spindles infinitely thin.

Now, as the two curved sides of each of the new teeth mutually terminate in the point or edge of concourse, it is clear that the distance OF of the point of one of these new teeth from the centre F of the wheel will be the greatest true radius the wheel will admit of. And, when a spindle E has been moved till the centre A of the following spindle is in the line GF of the centres, the spindle A may, in its turn, be moved by the succeeding tooth TYV; and then it will be no longer necessary for the tooth ROS to move the cylindric spindle E. The tooth ROS, therefore, may be terminated at the point X where it touches the spindle E, when the centre of the succeeding spindle is in the line of the centres; and the distance XF of that point

of contact from the centre of the wheel will be the least true radius the wheel will admit of. It will be proper to give the true radius of the wheel a mean length between OF and XF, and to file or round off the point of the tooth.

The teeth of the wheel being thus constructed, it is obvious that they will not move the spindles till their centres have arrived at the line of centres; and that the spindles, on the contrary, will move these teeth by impelling them towards the line of the centres GF, and until their centres have arrived at that line.

The sides TZ and S&, of the vacuities sunk in the primitive wheel, being directed towards the centre F of the wheel, the rounding of the spindle which proceeds beyond the primitive circle of the lantern, ought to have the shape of an epicycloid, which has for its base the primitive circle of the lantern, and is generated by a circle having a diameter equal to the radius AF of the wheel. Hence a circular spindle does not appear proper to be carried towards the line of the centres, by the side TZ of the vacuity sunk into the primitive wheel. But the preceding spindle E, being conducted by the preceding tooth of the wheel, until the centre of the spindle A has arrived in the line of the centres, and the space TA which the right line TZ ought to make the spindle pass over, before it attains the line of the centres, being very short; the arc of the spindle on which the side TZ will slide, in driving that spindle, will be so minute that it may be taken for a small arc of an epicycloid; and of consequence, if there be any want of uniformity in the movement of the lantern by the wheel, during the little time the part TZ of the tooth moves the spindle, this deviation from uniformity will be too small to be sensible.

It may not be amiss to observe that, since the teeth of a wheel must, by impelling the spindles of a lantern, remove them from the line of the centres, and since no shocks need be feared in this method of moving a lantern, a lantern may, without any inconvenience, be caused to be moved by a wheel. But, since, on the other hand, the spindle of a lantern ought by impelling the teeth of a wheel to bring them nearer to the line of the centres, and since shocks may occur in this method of driving a wheel, it seems reasonable to conclude that a pinion is preferable to a lantern when a wheel is to be driven.

We may next proceed to consider the case, in which, knowing the number of teeth in a wheel, and the number of the leaves of the *pinion* upon which it is to act, with the distance of their centres, we wish to determine their primitive and true radii, as well as the form of the teeth of the wheel, and the leaves of the pinion. Here, having, as in the former instance, divided the

distance FB of the centres (fig. 13. pl. XXXII.) into two parts AF and AB, proportional to the number of the teeth of the wheel, and leaves of the pinion respectively, these parts will be the primitive radii of the wheel and the pinion; and if there be described with these two parts as radii, from the points F and B as centres, two circumferences AQR, ATX, touching each other in the point A, they will be those of the primitive wheel and pinion.

It is common to shape a wheel so that the breadth of the teeth is equal to that of the vacuities, which is called by the French—*Fendre une roue tant plein que vuide.* In this case, divide the primitive circumference of the wheel into twice as many equal parts as it ought to have teeth, in order to fix the teeth CA, LQ, &c. of these teeth, and the vacuities AL, GQ, &c. which ought to be interposed. But if it be proposed that the teeth should fill more space than the vacuities, as is proper in certain circumstances, we must first divide the primitive circumference into as many equal parts CL, LG, &c. as it ought to have teeth; and afterwards divide each part, such as CL, into two other parts, CA, AL, one of them equal to the breadth which we would give to each tooth, and the other equal to the interval proposed to be put between two teeth. The feet CA, LQ, &c. of all the teeth being determined upon the primitive circumference of the wheel, draw through the extremities of these teeth, towards the centre of the wheel, right lines C*c*, A*a*, L*l*, Q*q*, &c. nearly equal to the breadth CA, LQ, of these feet, to mark out the straight flanks of the teeth; and through the extremities of each foot, as CA, let there be drawn two equal epicycloids CP, AP, whose generating circle AEY has the radius AB, of the pinion, for its diameter, and both of which have the primitive circumference of the wheel for the base. These epicycloids, when traced out, will include those parts of the teeth which project beyond the primitive circle of the wheel, in such manner, that the right line FP, drawn from the centre of the wheel to the point P, of concourse, of the two epicycloids of one tooth, will be the greatest true radius which the wheel admits, relatively to the spaces given to the teeth, and to the intervening vacuities.

Having divided the primitive circumference of the pinion into as many equal parts OH, HS, &c. as it ought to have leaves, each part, as OH, must again be divided into two other parts O*o*, *o*H, one equal to the thickness we would give to the leaf, and the other to the breadth of the vacuity proposed to be left between two leaves; giving to *o*H a breadth rather exceeding that of a tooth of the wheel, to furnish suitable play to the engagement. All the breadths O*o*, H*h*, &c. being thus deter-

mined, draw right lines a little longer than the projection PP, of the teeth of the wheel, beyond their primitive circle, through their extremities, towards the centre B of the pinion; and these lines will serve as flanks to the leaves of the pinion, and will determine the vacuities in which the teeth of the wheel will act with the proper play. Then describe through the extremities of the straight sides of each leaf two epicycloids, as *om*, *om*, whose generating circle AVF has for diameter the radius of the wheel, and both of which have for base the primitive circumference of the pinion: these epicycloids being traced out, will contain between them the parts of the leaves which project beyond the primitive circle of the pinion, so that the right line B*m* drawn from the centre of the pinion to the point of concourse *m* of the two epicycloids of the same leaf will be the greatest true radius that the pinion will admit of, relatively to the thickness of its leaves. The parts of the teeth of both wheel and pinion which are left unshaded in the figure may be rounded off, being never exposed to mutual action upon one another.

The preceding directions may suffice to convey a tolerably distinct notion of the scientific method of forming teeth of wheels to act with either pinions or lanterns, when the motion is communicated in the same plane: our next business is to speak of the teeth of crown-wheels, when driving either a lantern, or another wheel, their axles being in different planes. The space assigned to this article compels us to confine ourselves to the case of a crown-wheel driving a lantern, whose spindles are ranged in the surface of a cone, in which case the teeth must be shaped by means of a spherical epicycloid*. Here the first thing is to trace out the teeth of a wheel as though it had to drive a lantern with spindles infinitely thin, observing to leave for the play of the engagement small void places between the feet of all the teeth. Then, having made a lantern with conical spindles, all the summits of which converge to the centre C of the spherical zone, (figs. 1, 2. pl.

* Let there be a right cone, the summit of which C remains immoveable: if the base of this cone be made to revolve on any plane RAS (figs. 1, 2. pl. XXXV.) placed at pleasure in respect of the point C, and if we imagine a style or tracer situated in the point A of the circumference of the revolving circle, this style A will describe during its motion a curve called *a spherical epicycloid*. This curve has not, that we are aware of, been treated at large in an English work; but the curious reader may consult the following papers in foreign publications. Jacobi Hermanni de Epicycloidibus sphœricis. Comment. Acad. Petropol. tom. 1. an. 1726;—De la Hire Traité des Epicycloides, et de leurs usages dans les Méchaniques. Hist. acad. roy. Paris. 1730, tom. 9;—Probleme sur les Epicycloides spheriques, par M. Bernoulli, Mem. Acad. Roy. Par. 1732;—Des Epicycloides spheriques, par M. Clairaut, Do. an. 1732;—A. J. Lexel, de Epicycloidibus in superficie sphæricа descriptis. Act. Acad. Imp. Petropol. 1779. P. 2. p. 49.

XXXV.) in which the epicycloidal teeth have been cut, mark on the exterior surface of this zone the diameter which one spindle has at the place A, that answers to such surface; and mark, likewise, on the interior surface of the same belt, the diameter which the same spindle has at the point *a* where it cuts that surface.

The diameters which the spindles will have in the opposite surfaces of the toothed spherical zone, being marked upon these surfaces, take upon the same the chords of half the arcs to which these diameters answer. These chords, which will not be sensibly longer than the radii of a spindle, measured at the places where it is cut by the two spherical surfaces of the zone, being taken for radii; describe on the exterior and interior faces of each tooth as many little arcs as can well be, having their centres in the epicycloids, between which these faces are contained. Then, making curves to touch all these little arcs, such as OM, VN, which will necessarily be parallel to the epicycloids first traced out, and which will form the curved parts of the new teeth, proper to drive the conical spindle already spoken of, make in the rim of the wheel, below the primitive circle RES, hollows such as VXYZ, terminated by the planes which pass through the axis of the wheel and the origins V, and Y, of the curves parallel to the epicycloids. The curves OM and VN, and the straight flanks OP and VX, of every new tooth, being traced upon the interior and exterior surfaces of the spherical zone, let the teeth be cut so that a right line fixed by its extremity at the centre C of the dentated zone, being carried along the sides POM, XVN, of the exterior surface of each tooth, may be applied exactly upon the lateral surfaces of these teeth; then will be had a proper wheel to move the lantern with conical spindles, for which it has been constructed.

Though figs. 1, 2. exhibit only spherical epicycloids, containing the exterior faces of the first teeth, proper to move infinitely thin spindles, and though to avoid confusion, those have been suppressed which ought to contain the interior faces of the same teeth; we have, nevertheless, traced out all the curves which must be drawn parallel to these epicycloids in order to reform the first teeth, and put them in a state to move uniformly, a lantern with conical spindles, the common vertex of which is in the axis of the wheel. Also as the small arcs of circles which ought to have their centres in the spherical epicycloids, and through which it is requisite to draw the curves parallel to these epicycloids, might have caused confusion had they been traced upon the faces of all the teeth, they have been described to form only one exterior side of that tooth which is marked H.

Camus's dissertation, which occupies more than 100 pages in his Course, gives many other useful directions for the formation of teeth for different purposes, and exhibits several ingenious rules for the calculation of the relative numbers of the teeth in clock-work, and other machinery. As, however, the other parts of Camus's Course contain but little that is important and valuable in the present advanced state of mathematical knowledge, we are glad to be able to refer the English reader to a translation of that part of his work alone which relates to the present subject, and which has been recently published by Mr. Taylor, of the Architectural Library, Holborn.

The preceding are some of the best methods suggested by theory for the formation of the teeth of wheels; but it is seldom indeed that any of them are made use of by practical mechanics. Among them various methods are practised, almost every celebrated millwright or engineer having his favourite construction: of these we shall only describe one in this place; and that, being tolerably easy in application, allowing much strength to the teeth, while it is pretty free from friction in comparison with many practical methods, may sometimes, perhaps, be safely adopted. Let A and B (fig. 11. pl. XXXV.) be two spur-wheels of different diameters, of which the cogs are intended to work into each other half the pitch. The dotted circular arcs GH, EF, touching each other between *s* and *d*, are the centre or pitch lines, from which the teeth are formed. If the teeth of both wheels are iron, as is generally the case in the first motions of works, those teeth are then made nearly both of a size at the pitch line: but if the teeth of one be wood and the other iron, then the iron ones are made to have a good deal less pitch than the wooden ones; for then they are found to wear better. In the figure both are supposed of iron. Suppose the wheels to move from G towards H, and from E towards F, and that the sides of the teeth at *b*, *c*, and *d*, *e*, are in contact. From *b* as a centre with a radius equal to *bp*, describe the arcs *pd*, *lm*; from *d* as a centre with the same radius the arcs *hi*, *fg*, *ck*. Thus the same opening of the compasses, and a centre chosen where the wheels are in contact on the pitch line, will mark the contour of the upper part of a tooth of one wheel, and the lower part of a corresponding tooth of the other wheel: and by taking several centres on the two pitch lines, the various teeth may be formed. To prevent the cogs from *bottoming*, as the workmen call it, let the lower part *re* of one tooth be made rather longer than the upper part *pd* of the other which is to play into it. The way in which cogs thus constructed will work into one another may be understood by considering the

motion of two of them, n and o for example: when they first come into contact they will appear as at the curve xb PZ; when they arrive at Q the same sides will appear as in the dotted lines there represented; and when the same arrive at RS, they are in contact on their middle points.

In bevel work (see fig. 7. pl. III.) when this method of forming the teeth is adopted, the radii hy, gy, of the wheels must not be taken as those of the spur-wheel; but drawing a line through y perpendicular to xy, till it meets xg, and xh, produced, the segments of that line intercepted between y, and the produced lines xg, xh, must be used as the radii of the spur-wheels, and the other part of the construction will be as above. The line through y drawn perpendicular to xy, is called by millwrights *square of the bevel*. For more on the subject of bevel geer, consult the introductory part of this volume. And for Mr. Maudslay's contrivance for *cutting* teeth of wheels, see the article TURNING.

A very ingenious disquisition on the theory and practice of forming teeth and pinions, &c. is given by M. Hachette in his *Traité des Machines;* but the illustrative plates are too numerous and too large to be conveniently introduced into this work.

TELEGRAPH (derived from τηλε and γραφω), is the name very properly given to an instrument, by means of which information may be almost instantaneously conveyed to a considerable distance.

The telegraph, though it has been generally known and used by the moderns only for a few years, is by no means a modern invention. There is reason to believe that amongst the Greeks there was some sort of telegraph in use. The burning of Troy was certainly known in Greece very soon after it happened, and before any person had returned from thence. Now that was altogether so tedious a piece of business, that conjecture never could have supplied the place of information. A Greek play begins with a scene, in which a watchman descends from the top of a tower in Greece, and gives the information that Troy was taken. "I have been looking out these ten years (says he) to see when that would happen, and this night it is done." Of the antiquity of a mode of conveying intelligence quickly to a great distance this is certainly a proof.

The Chinese, when they send couriers on the great canal, or when any great man travels there, make signals by fire from one day's journey to another, to have every thing prepared; and most of the barbarous nations used formerly to give the alarm of war by fires lighted on the hills or rising grounds.

Polybius calls the different instruments used by the ancients for communicating information πυρσειαι, *pyrsiæ*, because the

signals were always made by means of fire. At first they communicated information of events merely by torches; but this method was of little use, because it was necessary beforehand to fix the meaning of every particular signal. Now as events are exceedingly various, it was impossible to express the greater number of them by any premeditated contrivance. It was easy, for instance, to express by signals that a fleet had arrived at such a place, because this had been foreseen, and signals accordingly had been agreed upon to denote it; but an unexpected revolt, a murder, and such accidents, as happen but too often, and require an immediate remedy, could not be communicated by such signals; because to foresee them was impossible.

A new method was invented by Cleoxenus (others say by Democritus), and very much improved by Polybius, as he himself informs us. He describes this method as follows: Take the letters of the (Greek) alphabet, and divide them into five parts, each of which will consist of five letters, except the last division, which will have only four. Let these be fixed on a board in five columns. The man who is to give the signals is then to begin by holding up two torches, which he is to keep aloft till the other party has also shown two. This is only to show that both sides are ready. These first torches are then withdrawn. Both parties are provided with boards, on which the letters are disposed as formerly described. The person, then, who gives the signal is to hold up torches on the left to point out to the other party from what column he shall take the letters as they are pointed out to him. If it is to be from the first column, he holds up one torch; if from the second, two; and so on for the others. He is then to hold up torches on the right, to denote the particular letter of the column that is to be taken. All this must have been agreed on beforehand. The man who gives the signals must have an instrument (διοπτραν), consisting of two tubes, and so placed as that, by looking through one of them, he can see only the right side, and through the other only the left, of him who is to answer. The board must be set up near this instrument; and the station on the right and left must be surrounded with a wall (παραπεφαχθαι) ten feet broad, and about the height of a man, that the torches raised above it may give a clear and strong light, and that when taken down they may be completely concealed. Let us now suppose that this information is to be communicated—*A number of the auxiliaries, about a hundred, have gone over to the enemy.* In the first place, words must be chosen that will convey the information in the fewest letters possible; as, *A hundred Cretans have deserted,* Κρετες εκατον αφ' ημων ηυτομολησαν. Having written down

this sentence, it is conveyed in this manner. The first letter is a K, which is in the second column; two torches are therefore to be raised on the left hand, to inform the person who receives the signals to look into that particular column. Then five torches are to be held up on the right, to mark the letter *k*, which is the left in the column. Then four torches are to be held up on the left to point out the ϱ (*r*), which is in the fourth column, and two on the right to show that it is the second letter of that column. The other letters are pointed out in the same manner.—Such was the *pyrsia* or telegraph recommended by Polybius See Polyb. Lib. x. Ext. 7. cap. 2.

But neither this nor any other method mentioned by the ancients seems ever to have been brought into general use: nor does it appear that the moderns had thought of such a machine as a telegraph till the year 1663, when the Marquis of Worcester, in his Century of Inventions, affirmed that he had discovered "a method by which, at a window, as far as eye can discover black from white, a man may hold discourse with his correspondent, without noise made or notice taken; being according to occasion given, or means afforded, *ex re nata,* and no need of provision beforehand; though much better if foreseen, and course taken by mutual consent of parties." This could be done only by means of a telegraph, which in the next sentence is declared to have been rendered so perfect, that by means of it the correspondence could be carried on "by night as well as by day, though as dark as pitch is black."

Dr. Hooke, whose genius as a mechanical inventor was perhaps never surpassed, delivered a "Discourse to the Royal Society, May 21, 1684, showing a way how to communicate one's mind at great distances." In this discourse, he asserted the possibility of conveying intelligence from one place to another at the distance of 30, 40, 100, 120, &c. miles, "in as short a time almost as a man can write what he would have sent." He takes to his aid the then recent invention of the telescope, and explains the method by which characters exposed at one station may be rendered plain and distinguishable at the others. He directs, "First, for the stations; if they be far distant, it will be necessary that they should be high, and lie exposed to the sky; that there be no higher hill, or part of the earth beyond them, that may hinder the distinctness of the characters that are to appear dark, the sky beyond them appearing white: by which means also the thick and vaporous air near the ground will be passed over and avoided." "Next, the height of the stations is advantageous, upon the account of the refractions or inflections of the air." "Next, in choosing of these stations, care must be taken, as near as may be, that there be no hill that

interposes between them, that is almost high enough to touch the visible ray; because in such cases the refraction of the air of that hill will be very apt to disturb the clear appearance of the object." "The next thing to be considered is, what telescopes will be necessary for such stations." "One of these telescopes must be fixed at each extreme station, and two of them in each intermediate; so that a man for each glass, sitting and looking through them, may plainly discover what is done in the next adjoining station, and with his pen write down on paper the characters there exposed in their due order; so that there ought to be two persons at each extreme station, and three at each intermediate; so that, at the same time, intelligence may be conveyed forwards and backwards." "Next, there must be certain times agreed on, when the correspondents are to expect; or else there must be set at the top of the pole, in the morning, the hour appointed by either of the correspondents for acting that day: if the hour be appointed, pendulum clocks may adjust the moment of expectation and observing." "Next, there must be a convenient apparatus of characters, whereby to communicate any thing with great ease, distinctness, and secresy. And those must be either day characters or night characters." The day characters "may all be made of three slit deals:" the night characters "may be made with links, or other lights, disposed in a certain order." The doctor invented 24 simple characters, each constituted of right lines, for the letters of the alphabet; and several single characters, made up of semicircles, for whole sentences. He recommended that three very long masts or poles should be placed vertically, and joined at top by one strong horizontal beam; that a large screen should be placed at one of the upper corners of this frame, behind which all the deal-board characters should hang, and by the help of proper cords should quickly be drawn forwards to be exposed, and then drawn back again behind the screen. "By these means," says the doctor, "all things may be made so convenient that the same character may be seen at Paris, within a minute after it hath been exposed at London, and the like in proportion for greater distances; and that the characters may be exposed so quick after one another, that a composer shall not much exceed the exposer in swiftness." Among the uses of this contrivance, the inventor specifies these: "The first is for cities or towns besieged; and the second for ships upon the sea; in both which cases it may be practised with great certainty, security, and expedition." The whole of Dr. Hooke's paper was published in Derham's collection of his *Experiments and Observations;* from which it appears, that he had brought the telegraph to a state of far greater maturity and perfection

than M. Amontons, who attempted the same thing about the year 1702; and indeed to a state little inferior to several which have been proposed during the last thirty years.

It was not, however, till the French revolution, that the telegraph was applied to useful purposes. Whether M. Chappe, who is said to have invented the telegraph first used by the French about the end of 1793, knew any thing of Hooke's or of Amonton's invention, it is impossible to say; but his telegraph was constructed on principles nearly similar. The manner of using this telegraph was as follows: at the first station, which was on the roof of the palace of the Louvre at Paris, M. Chappe, the inventor, received in writing, from the committee of public welfare, the words to be sent to Lisle, near which the French army at that time was. An upright post was erected on the Louvre, at the top of which were two transverse arms, moveable in all directions by a single piece of mechanism, and with inconceivable rapidity. He invented a number of positions for these arms, which stood as signs for the letters of the alphabet; and these, for the greater celerity and simplicity, he reduced in number as much as possible. The grammarian will easily conceive that sixteen signs may amply supply all the letters of the alphabet, since some letters may be omitted, not only without detriment, but with advantage. These signs, as they were arbitrary, could be changed every week; so that the sign of B for one day might be the sign of M the next; and it was only necessary that the persons at the extremities should know the key. The intermediate operators were only instructed generally in these sixteen signals; which were so distinct, so marked, so different the one from the other, that they were easily remembered. The construction of the machine was such that each signal was uniformly given in precisely the same manner at all times: it did not depend on the operator's manual skill; and the position of the arm could never, for any one signal, be a degree higher or a degree lower, its movement being regulated mechanically.

M. Chappe having received at the Louvre the sentence to be conveyed, gave a known signal to the second station, which was Mont Martre, to prepare. At each station there was a watch-tower, where telescopes were fixed, and the person on watch gave the signal of preparation which he had received, and this communicated successively through all the line, which brought them all into a state of readiness. The person at Mont Martre then received, letter by letter, the sentence from the Louvre, which he repeated with his own machine: and this was again repeated from the next height, with inconceivable rapidity, to the final station at Lisle.

The first description of the telegraph was brought from Paris to Frankfort on the Maine by a former member of the parliament of Bourdeaux, who had seen that which was erected on the mountain of Belville. As given by Dr. Hutton from some of the English papers, it is as follows. AA is a beam or mast of wood placed upright on a rising ground (fig. 1. pl. XXXIII.), which is about fifteen or sixteen feet high. BB is a beam or balance moving upon the centre AA. This balance-beam may be placed vertically or horizontally, or any how inclined, by means of strong cords, which are fixed to the wheel D, on the edge of which is a double groove to receive the two cords. This balance is about eleven or twelve feet long, and nine inches broad, having at the ends two pieces of wood CC, which likewise turn upon angles by means of four other cords that pass through the axis of the main balance, otherwise the balance would derange the cords; the pieces C are each about three feet long, and may be placed either to the right or left, straight or square, with the balance-beam. By means of these three the combination of movement is very extensive, remarkably simple, and easy to perform. Below is a small wooden gouge or hut, in which a person is employed to observe the movements of the machine. In the mountain nearest to this, another person is to repeat these movements, and a third to write them down. The time taken up for each movement is twenty seconds; of which the motion alone is four seconds, the other 16 the machine is stationary. Two working models of this instrument were executed at Frankfort, and sent by Mr. W. Playfair to the Duke of York: and hence the plan and alphabet of the machine came to England.

Various experiments were in consequence tried upon telegraphs in this country; and one was soon after set up by government in a chain of stations from the Admiralty-Office to the sea-coast. It consisted of six octagon boards, each of which is poised upon an axis in a frame, in such a manner that it could be either placed vertically, so as to appear with its full size to the observer at the nearest station, as in fig. 2. or to become invisible to him by being placed horizontally, as in fig. 3. so that the narrow edge alone was exposed, which narrow edge is from a distance invisible. Fig. 2. is a representation of this telegraph, with the parts all shut, and the machine ready to work. T, in the officer's cabin, is the telescope pointed to the next station. Fig. 3. is a representation of the machine not at work, and with the ports all open. The opening of the first port (fig. 2.) expresses *a*, the second *b*, the third *c*, the fourth *d*, the fifth *e*, and the sixth *f*, &c.

Six boards make 36 changes, by the most plain and simple

mode of working; and they will make many more if more were necessary; but as the real superiority of the telegraph over all other modes of making signals consists in its making letters, we do not think that more changes than the letters of the alphabet, and the ten arithmetical ciphers, are necessary; but, on the contrary, that those who work the telegraphs should avoid communicating by words or signs agreed upon to express sentences; for that is the sure method never to become expert at sending unexpected intelligence accurately.

Several other telegraphs have been proposed, to remedy the defects to which the instrument is still liable. The dial-plate of a clock would make an excellent telegraph, as it might exhibit 144 signs so as to be visible at a great distance. A telegraph on this principle, with only six divisions instead of twelve, would be simple and cheap, and might be raised 20 or 30 feet high above the building without any difficulty: it might be supported on one post, and therefore turn round, and the contrast of colours would always be the same.

A very ingenious improvement of the telegraph has been proposed in the Gentleman's Magazine. It consists of a semicircle, to be properly elevated, and fixed perpendicularly on a strong stand. The radius 12 feet; the semicircle consequently somewhat more than 36. This is to be divided into 24 parts. Each of these will therefore comprise a space of 18 inches, and an arch of 7° 30′ on the circumference. These 24 divisions to be occupied by as many circular apertures of six inches diameter; which will leave a clear space of six inches on each side between the apertures. These apertures, beginning from the left, to denote the letters of the alphabet, omitting K, J consonant, V, X, and Q, as useless for this purpose. There are then 21 letters. The four other spaces are reserved for signals. The instrument to have an index moveable by a windlass on the centre of the semicircle, and having two tops, according as it is to be used in the day or night; one, a circular top, of lacquered iron or copper, of equal diameter with the apertures (and which consequently will eclipse any of them against which it rests); the other, a spear or arrow-shaped top, black, and highly polished, which in standing before any of the apertures in the day-time will be distinctly visible. In the night, the apertures to be reduced by a diaphragm fitting close to each, so as to leave an aperture of not more than two inches' diameter. The diaphragm to be of well-polished tin; the inner rim lacquered black half an inch. All the apertures to be illuminated, when the instrument is used in the night-time, by small lamps; to which, if necessary, according to circumstances, convex lenses may be added, fitted into each diaphragm, by which the

light may be powerfully concentrated and increased. Over each aperture one of the five prismatic colours least likely to be mistaken (the remaining two being less distinguishable, and not wanted, are best omitted) to be painted; and, in their natural order, on a width of eighteen inches and a depth of four, red, orange, yellow, green, blue; or, still to heighten the contrast, and render immediately successive apertures more distinguishable, red, green, orange, blue, yellow. The whole inner circle beneath and between the apertures to be painted black.

When the instrument is to be used, the index to be set to the signal apertures on the right. All the apertures to be covered or dark when it begins to be used, except that which is to give the signal. A signal gun to be fired to apprise the observer. If the index is set to the first aperture, it will denote that words are to be expressed; if to the second, that figures; if to the third, that the figures cease; and that the intelligence is carried on in words. When figures are to be expressed, the alternate apertures from the left are taken in their order, to denote from 1 to 10 inclusively; the second from the right denotes 100; the fifth 1000. This order, and these intervals, are taken to prevent any confusion in so peculiarly important an article of the intelligence to be conveyed.

Perhaps, however, few of the telegraphs hitherto offered to the public exceed the following, either in simplicity, cheapness, or facility in working; and it might, perhaps, with a few trifling additions, be made exceedingly distinct. It is thus described in the *Repertory of Arts and Manufactures:* For a nocturnal telegraph, let there be four large patent reflectors, lying on the same plane, parallel to the horizon, placed on the top of an observatory. Let each of these reflectors be capable, by means of two winches, either of elevation or depression to a certain degree. By elevating or depressing one or two of the reflectors, eighteen very distinct arrangements may be produced, as the following scheme will explain.

A	B	D	E	F	G
0 000	0 0 00	0 00 0	0 000	000 0	0 00 0

I	K	L	M	N	O
00 0 0	000 0	00 00	0 0 0 0	0 0 00	00 00

P	R	S	T	U	Y
0 0 0 0	00 0 0	00 0 0	0 00 0	0 0 00	0 00 0

For the sake of example, the above arrangements are made to answer to the most necessary letters of the alphabet; but alterations may be made at will, and a greater number of changes produced, without any addition to the reflectors. In the first observatory there need only be a set of single reflectors; but in the others each reflector should be double, so as to face both the preceding and subsequent observatory; and each observatory should be furnished with two telescopes. The proper diameter of the reflectors, and their distance from each other, will be ascertained by experience; and it must be observed, that each reflector, after every arrangement, must be restored to its place.

To convert this machine into a diurnal telegraph, nothing more is necessary than to insert, in the place of the reflectors, gilt balls, or any other conspicuous bodies.

Since these inventions were made public, telegraphs have been brought to so great a degree of perfection, that they now convey information speedily and distinctly, and are so much simplified, that they can be constructed and maintained at little expense. The advantages, too, which result from their use are almost inconceivable. Not to speak of the speed with which information is communicated and orders given in time of war, by means of them, the whole kingdom could be prepared in an instant to oppose an invading enemy. A telegraph might be

also used by commercial men to convey a commission, cheaper and speedier than an express can travel. An establishment of telegraphs might be made like that of the post; and instead of being an expense, it would produce a revenue. Something of this kind was about twenty years ago set up to facilitate the intercourse between Norwich and Yarmouth; and a new and extensive plan of the same kind is now (October 1825) in agitation.

THERMOMETER, an instrument for ascertaining the temperature, that is, for measuring the degree of heat or cold in any body. The thermometer was invented about the beginning of the 15th century; but, like many other useful inventions, it has been found impossible to ascertain to whom the honour of it belongs.

The first form of this instrument for measuring the degrees of heat and cold was the air-thermometer. It is a well-known fact that air expands with heat so as to occupy more space than it does when cold, and that it is condensed by cold so as to occupy less space than when warmed, and that this expansion and condensation is greater or less according to the degree of heat or cold applied. The principle, then, on which the air-thermometer was constructed is very simple. The air was confined in a tube by means of some coloured liquor; the liquor rose or fell according as the air became expanded or condensed.

This instrument was extremely defective: for the air in the tube was not only affected by the heat and cold of the atmosphere, but also by its weight.

The air being found improper for measuring with accuracy the variations of heat and cold according to the form of the thermometer which was first adopted, another fluid was proposed about the middle of the 17th century by the Florentine academy. This fluid was spirit of wine, or alcohol, as it is now generally named. The alcohol being coloured, was inclosed in a very fine cylindrical glass tube previously exhausted of its air, having a hollow ball at the lower end, and hermetically sealed at the other end. The ball and tube are filled with rectified spirit of wine to a convenient height, when the weather is of a mean temperature, which may be done by inverting the tube into a vessel of stagnant coloured spirit, under a receiver of the air-pump, or in any other way. When the thermometer is properly filled, the upper end is heated red-hot by a lamp, and then hermetically sealed, leaving the included air of about $\frac{1}{3}$ of its natural density, to prevent the air which is in the spirit from dividing it in its expansion. To the tube is applied a scale, divided from the middle into 100 equal parts, upwards and downwards.

As spirit of wine is capable of a very considerable degree of rarefaction and condensation by heat and cold, when the heat of the atmosphere increases the spirit dilates, and consequently rises in the tube; and when the heat decreases the spirit descends, and the degree or quantity of the motion is shown by a scale.

The spirit of wine thermometer was not subject to some of the inconveniences which attended the air-thermometer. In particular, it was not affected by variations in the weight of the atmosphere: accordingly it soon came into general use among philosophers. It was, at an early period, introduced into Britain by Mr. Boyle. To this instrument, as then used, there are, however, many objections. The liquor was of different degrees of strength; and therefore different tubes filled with it, when exposed to the same degree of heat, would not correspond. There was also another defect; the scale which was adjusted to the thermometer did not commence at any fixed point. The highest term was adjusted to the great sun-shine heats of Florence, which are too variable and undetermined; and frequently the workman formed the scale according to his own fancy. While the thermometer laboured under such disadvantages it could not be of general use.

To obtain some fixed unalterable point by which a determined scale might be discovered, to which all thermometers might be accurately adjusted, was the subject which next drew the attention of philosophers. Mr. Boyle, who seems at an early period to have studied this subject with much anxiety, proposed the freezing of the essential oil of aniseeds as a convenient point for graduating thermometers; but this opinion he soon laid aside. Dr. Halley next proposed that thermometers should be graduated in a deep pit under ground, where the temperature both in winter and summer is pretty uniform; and that the point to which the spirit of wine should rise in such a subterraneous place should be the point from which the scale should commence. But this proposal was evidently attended with such inconveniences, that it was soon abandoned. He made experiments on the boiling point of water, of mercury, and of spirit of wine; and he seems rather to give a preference to the spirit of wine. He objected to the freezing of water as a fixed point, because he thought that it admitted considerable latitude.

It seems to have been reserved to the genius of Newton to determine this important point, on which the accuracy and value of the thermometer depends. He chose, as fixed, those points at which water freezes and boils; the very points which

the experiments of succeeding philosophers have determined to be the most fixed and convenient. Sensible of the disadvantages of spirit of wine, he tried another liquor which was homogeneous enough, capable of a considerable rarefaction, about 15 times greater than spirit of wine. This was linseed oil. It has not been observed to freeze even in very great colds, and it bears a heat about four times that of water before it boils. With these advantages it was made use of by Newton, who discovered by it the comparative degree of heat for boiling water, melting wax, boiling spirit of wine, and melting tin; beyond which it does not appear that this thermometer was applied. The method he used for adjusting the scale of this oil-thermometer was as follows: Supposing the bulb, when immerged in thawing snow, to contain 10,000 parts, he found the oil expand by the heat of the human body so as to take up $\frac{1}{39}$th more space, or 10,256 such parts; and by the heat of water boiling strongly 10,725; and by the heat of melting tin 11,516. So that reckoning the freezing point as a common limit between heat and cold, he began his scale there, marking it 0, and the heat of the human body he made 12°; and consequently, the degrees of the heat being proportional to the degrees of rarefaction, or 256 : 725 : : 12 : 34, this number 34 will express the heat of boiling water; and by the same rule, 72 that of melting tin. This thermometer was constructed in 1701.

To the application of common oil as a measure of heat and cold there are strong objections. It is so viscid, that it adheres too strongly to the sides of the tube. On this account it ascends and descends too slowly in case of a sudden heat or cold. In a sudden cold, so great a proportion remains adhering to the sides of the tube after the rest has subsided, that the surface appears lower than the corresponding temperature of the air requires. An oil thermometer is therefore not a proper measure of heat and cold.

All the thermometers hitherto proposed were liable to many inconveniences, and could not be considered as exact standards for pointing out the various degrees of temperature. This led Reaumur to attempt a new one, an account of which was published, in the year 1730, in the Memoirs of the Academy of Sciences. This thermometer was made with spirit of wine. He took a large ball and tube, the dimensions and capacities of which were known: he then graduated the tube, so that the space from one division to another might contain 1000th part of the liquor; the liquor containing 1000 parts when it stood at the freezing point. He adjusted the thermometer to the freezing point by an artificial congelation of water: then putting the ball of his thermometer and part of the tube into

boiling water, he observed whether it rose 80 divisions: if it exceeded these, he changed his liquor, and by adding water lowered it, till upon trial it should just rise 80 divisions; or if the liquor, being too low, fell short of 80 divisions, he raised it by adding rectified spirit to it. The liquor thus prepared suited his purpose, and served for making a thermometer of any size whose scale would agree with his standard.

This thermometer was far from being perfect. As the bulbs were three or four inches in diameter, the surrounding ice would be melted before its temperature could be propagated to the whole spirits in the bulb, and consequently the freezing point would be marked higher than it should be. Dr. Martine accordingly found, that instead of coinciding with the 32d degree of Fahrenheit, it corresponded with the 34th, or a point a little above it. Reaumur committed a mistake also respecting the boiling point; for he thought that the spirit of wine, whether weak or strong, when immerged in boiling water, received the same degree of heat with the boiling water. But it is well known that highly rectified spirit of wine cannot be heated much beyond the 175th degree of Fahrenheit, while boiling water raises the quicksilver 37 degrees higher. There is another thermometer that goes by the name of *Reaumur*'s, which shall be afterwards described.

At length a different fluid was proposed, by which thermometers could be made free from most of the defects hitherto mentioned. This fluid was mercury, and seems first to have occurred to Dr. Halley in the last century; but was not adopted by him, on account of its having a smaller degree of expansibility than the other fluids used at that time. Boerhaave says that the mercurial thermometer was first constructed by Olaus Roemer; but the honour of this invention is generally given to Fahrenheit of Amsterdam, who presented an account of it to the Royal Society of London in 1724.

Mercury is far superior to alcohol and oil, and is much more manageable than air. 1. As far as the experiments already made can determine, it is of all the fluids hitherto employed in the construction of thermometers that which measures most exactly equal differences of heat by equal differences of its bulk: its dilatations are in fact very nearly proportional to the augmentations of heat applied to it. 2. Of all liquids it is the most easily freed from air. 3. It is fitted to measure high degrees of heat and cold. It sustains a heat of 600° of Fahrenheit's scale, and does not congeal till it falls 39 or 40 degrees below 0. 4. It is the most sensible of any fluid to heat and cold, even air not excepted. Count Rumford found that mercury was heated from the freezing to the boiling point in 58 seconds,

while water took two minutes 13 seconds, and common air 10 minutes and 17 seconds. 5. Mercury is a homogeneous fluid, and every portion of it is equally dilated or contracted by equal variations of heat. Any one thermometer made of pure mercury is, *cæteris paribus*, possessed of the same properties with every other thermometer made of pure mercury. Its power of expansion is indeed about six times less than that of spirit of wine, but it is great enough to answer most of the purposes for which a thermometer is wanted.

The fixed points which are now universally chosen for adjusting thermometers to a scale, and to one another, are the boiling and freezing water points. The boiling water point, it is well known, is not an invariable point, but varies some degrees according to the weight and temperature of the atmosphere. In an exhausted receiver, water will boil with a heat of 98° or 100°; whereas in Papin's digester it will acquire a heat of 412°. Hence it appears that water will boil at a lower point, according to its height in the atmosphere, or to the weight of the column of air which presses upon it. In order to ensure uniformity therefore, in the construction of thermometers, it is now agreed that the bulb of the tube be plunged in the water when it boils violently, the barometer standing at 30 English inches (which is its mean height round London), and the temperature of the atmosphere 55°. A thermometer made in this way, with its boiling point at 212°, is called by Dr. Horsley *Bird's Fahrenheit*, because Mr. Bird was the first person who attended to the state of the barometer in constructing thermometers.

As artists may be often obliged to adjust thermometers under very different pressures of the atmosphere, philosophers have been at pains to discover a general rule which might be applied on all occasions. M. de Luc, in his *Recherches sur les Mod. de l'Atmosphere*, has given, from a series of experiments, an equation for the allowance on account of this difference, in Paris measure, which has been verified by Sir George Shuckburgh; also Dr. Horsley, Dr. Maskelyne, and Sir George Shuckburgh, have adapted the equation and rules to English measure, and have reduced the allowances into tables for the use of the artist. Dr. Horsley's rule, deduced from De Luc's, is this:

$$\frac{99}{8990000} \log. z - 92{\cdot}804 = h;$$

where h denotes the height of a thermometer plunged in boiling water, above the point of melting ice, in degrees of Bird's Fahrenheit, and z the height of the barometer in 10ths of an inch. From this rule he has computed the following table for finding the heights to which a good Bird's Fahrenheit will rise when plunged in boiling water, in all states of the barometer, from 27 to 31 English inches; which will serve, among other

uses, to direct instrument-makers in making a true allowance for the effect of the variation of the barometer, if they should be obliged to finish a thermometer at a time when the barometer is above or below 30 inches; though it is best to fix the boiling point when the barometer is at that height.

Equation of the Boiling Point.

Barometer.	Equation.	Difference.
31·0	+ 1·57	0·78
30·5	+ 0·79	0·79
30·0	0·00	0·80
29·5	− 0·80	0·82
29·0	− 1·62	0·83
28·5	− 2·45	0·85
28·0	− 3·31	0·86
27·5	− 4·16	0·88
27·0	− 5·04	

The numbers in the first column of this table express heights of the quicksilver in the barometer in English inches and decimal parts: the second column shows the equation to be applied, according to the sign prefixed, to 212° of Bird's Fahrenheit, to find the true boiling point for every such state of the barometer. The boiling point for all intermediate states of the barometer may be had with sufficient accuracy, by taking proportional parts, by means of the third column of differences of the equation. See Phil. Trans. lxiv. art. 30.; also Dr. Maskelyne's Paper, vol. lxiv. art. 20.

Sir George Shuckburgh also has given the following general table for the use of artists in constructing the thermometer, both according to his own observations and those of M. de. Luc.

Height of the Barometer.	Correct. of the boiling point.	Difference.	Correct. accord. to M. de Luc.	Difference.
	°		°	
26·0	− 7·09	·91	− 6·83	·90
26·5	− 6·18	·91	− 5·93	·89
27·0	− 5·27	·90	− 5·04	·88
27·5	− 4·37	·89	− 4·16	·87
28·0	− 3·48	·89	− 3·31	·86
28·5	− 2·59	·87	− 2·45	·83
29·0	− 1·72	·87	− 1·62	·82
29·5	− 0·85	·85	− 0·80	·80
30·0	0·00	·85	0·00	·79
30·5	+ 0·85	·84	+ 0·79	·78
31·0	+ 1·69		+ 1·57	

The Royal Society, fully apprised of the importance of adjusting the fixed points of thermometers, appointed a committee of seven gentlemen to consider of the best method for this purpose; and their report is published in the Phil. Trans. vol. lxvii. part ii. art. 37.

They observed, that though the boiling point be placed much higher on some of the thermometers now made than on others, yet this does not produce any considerable error in the observations of the weather, at least in this climate; for an error of $1\frac{1}{2}^\circ$ in the position of the boiling point will make an error only of half a degree in the position of 92°, and of not more than a quarter of a degree in the point of 62°. It is only in nice experiments, or in trying the heat of hot liquors, that this error in the boiling point can be of much importance.

In adjusting the freezing as well as the boiling point, the quicksilver in the tube ought to be kept of the same heat as that in the ball. When the freezing point is placed at a considerable distance from the ball, the pounded ice should be piled to such a height above the ball, that the error which can arise from the quicksilver in the remaining part of the tube, not being heated equally with that in the ball, shall be very small, or the observed point must be corrected on that account according to the following table:

Heat of the Air.	Correction.
42°	·00087
52	·00174
62	·00261
72	·00348
82	·00435

The correction in this table is expressed in 1000th parts of the distance between the freezing point and the surface of the ice: *e. g.* if the freezing point stands seven inches above the surface of the ice, and the heat of the room is 62, the point of 32° should be placed $7 \times \cdot 00261$, or ·018 of an inch lower than the observed point. A diagonal scale will facilitate this correction.

The committee observe, that in trying the heat of liquors, care should be taken that the quicksilver in the tube of the thermometer be heated to the same degree as that in the ball; or if this cannot be done conveniently, the observed heat should be corrected on that account; for the manner of doing which, and a table calculated for this purpose, we must refer to their excellent report in Phil. Trans. vol. lxvii. part ii. art. 37.

With regard to the choice of tubes, they ought to be exactly cylindrical. But though the diameter should vary a little, it is easy to manage that matter in the manner proposed by the Abbé Nollet, by making a small portion of the quicksilver, *e.g.* as much as fills up an inch or half an inch, slide backward and forward in the tube; and thus to find the proportions of all its inequalities, and from thence to adjust the divisions to a scale of the most perfect equality. The capillary tubes are preferable to others, because they require smaller bulbs, and they are also more sensible, and less brittle. The most convenient size for common experiments has the internal diameter about the 40th or 50th of an inch, about 9 inches long, and made of thin glass, that the rise and fall of the mercury may be better seen.

It is commonly observed of thermometers, that upon equal augmentations and diminutions of heat they seldom vary equally, though they are filled with the same liquor. To account for this circumstance it should be recollected, that the variation of a thermometer is directly as the capacity of the ball, and inversely as the base of the stem. Thus, if there be two mercurial thermometers, for example, and we call the capacities of the balls C and c, and the bases of the stems B and b, the variations will be as C to c directly, and as B to b inversely, or as $\frac{C}{B}$ to $\frac{c}{b}$. Consequently the variations will not be equal in those thermometers unless $\frac{C}{B} = \frac{c}{b}$: and this cannot be the case unless $C : c :: B : b$; therefore, to render the variations in the two thermometers equal, the capacities of their balls must be to each other as the bases of their cylindrical stems. See, on this subject, M. Durand's formula, given under the article THERMOMETER, in the *Pantologia.*

The next thing to be considered is of what number of degrees or divisions the scale ought to consist, and from what point it ought to commence. As the number of the divisions of the scale is an arbitrary matter, the scales which have been employed differ much from one another in this circumstance. Fahrenheit has made 180 degrees between the freezing and boiling water point. Amontons made 73, and Sir Isaac Newton only 34. There is, however, one general maxim, which ought to be observed: *That such an arithmetical number should be chosen as can easily be divided and subdivided, and that the number of divisions should be so great that there shall seldom be occasion for fractions.* The number 80 chosen by Reaumur answers extremely well in this respect, because it can be divided by several figures without leaving a remainder; but it is too small a number: the consequence of which is, that the

degrees are placed at too great a distance from one another, and fractions must therefore be often employed. We think, therefore, that 160 would have been a more convenient number. Fahrenheit's number, 180, is large enough; but when divided its quotient soon becomes an odd number.

As to the point at which the scale ought to commence, various opinions have been entertained. If we knew the beginning or lowest degree of heat, all philosophers would agree that the lowest point of the thermometer ought to be fixed there; but we know neither the lowest nor the highest degrees of heat, we observe only the intermediate parts. All that we can do, then, is to begin it at some invariable point, to which thermometers made in different places may easily be adjusted. If possible, too, it ought to be a point at which a natural well-known body receives some remarkable change from the effects of heat or cold. Fahrenheit began his scale at the point at which snow and salt congeal. Kirwan proposes the freezing point of mercury. Sir Isaac Newton, Hales, and Reaumur, adopted the freezing point of water. The objection to Fahrenheit's lowest point is, that it commences at an artificial cold seldom known in nature, and to which we cannot refer our feelings, for it is what few can ever experience. There would be several great advantages gained, we allow, by adopting the freezing point of mercury. It is the lowest degree of cold to which mercury can be applied as a measure; and it would render unnecessary the use of the signs plus and minus, and the extension of the scale below 0. But we object to it, that it is not a point well known; for few, comparatively speaking, who use thermometers, can have an opportunity of seeing mercury congealed. As to the other advantage to be gained by adopting the freezing point of mercury, namely, the abolition of negative numbers, we do not think it would counterbalance the advantage to be enjoyed by using a well-known point. Besides, it may be asked, Is there not a propriety in using negative numbers to express the degree of cold, which is a negative thing? Heat and cold we can only judge of by our feelings: the point then at which the scale should commence ought to be a point which can form to us a standard of heat and cold; a point familiar to us from being one of the most remarkable that occurs in nature, and therefore a point to which we can with most clearness and precision refer in our minds on all occasions. This is the freezing point of water chosen by Sir Isaac Newton, which of all the general changes produced in nature by cold is the most remarkable. It, or rather the melting point of ice, which does not vary with change of atmospheric pressure, is therefore the most convenient point for the thermometers to be used in the

temperate and frigid zones, or we may say over the globe, for even in the hottest countries of the torrid zone many of the mountains are perpetually covered with snow.

Having now explained the principles of the thermometer as fully as appears necessary in order to make it properly understood, we will here subjoin an account of those thermometers which are at present in most general use. These are Fahrenheit's, De l'Isle's, Reaumur's, and Celsius's. Fahrenheit's is used in Britain, De l'Isle's in Russia, Reaumur's in France, and Celsius's in Sweden. They are all mercurial thermometers.

Fahrenheit's thermometer consists of a slender cylindrical tube and a small longitudinal bulb. To the side of the tube is annexed a scale which Fahrenheit divided into 600 parts, beginning with that of the severe cold which he had observed in Iceland in 1709, or that produced by surrounding the bulb of the thermometer with a mixture of snow or beaten ice and sal ammoniac or sea salt. This he apprehended to be the greatest degree of cold, and accordingly he marked it, as the beginning of his scale, with 0; the point at which mercury begins to boil he conceived to show the greatest degree of heat, and this he made the limit of his scale. The distance between these two points he divided into 600 equal parts or degrees; and by trials, he found that the mercury stood at 32 of these divisions; when water just begins to freeze, or snow or ice just begin to thaw; it was therefore called the degree of the freezing point. When the tube was immersed in boiling water, the mercury rose to 212, which therefore is the boiling point, and is just 180 degrees above the former or freezing point. But the present method of making the scale of these thermometers, which is the sort in most common use, is first to immerge the bulb of the thermometer in ice or snow just beginning to thaw, and mark the place where the mercury stands, with 32; then immerge it in boiling water, and again mark the place where the mercury stands in the tube, with the num. 212, exceeding the former by 180; dividing therefore the intermediate space into 180 equal parts, will give the scale of the thermometer; which may afterwards be continued upwards and downwards at pleasure.

Other thermometers of a similar construction have been accommodated to common use, having but a portion of the above scale. They have been made of a small size and portable form, and adapted with appendages to particular purposes; and the tube with its annexed scale has often been enclosed in another thicker glass tube, also hermetically sealed, to preserve the thermometer from injury. And all these are called *Fahrenheit's thermometers*.

In 1733, M. De l'Isle of Petersburgh constructed a mercurial thermometer on the principles of Reaumur's spirit thermometer. In his thermometer, the whole bulk of quicksilver, when immerged in boiling water, is conceived to be divided into 100,000 parts; and from this one fixed point the various degrees of heat, either above or below it, are marked in these parts on the tube or scale, by the various expansion or contraction of the quicksilver, in all imaginable varieties of heat.—Dr. Martine apprehends it would have been better if De l'Isle had made the integer 100,000 parts, or fixed point, at freezing water, and from thence computed the dilatations or condensations of the quicksilver in those parts; as all the common observations of the weather, &c. would have been expressed by numbers increasing as the heat increased, instead of decreasing, or counting the contrary way. However, in practice it will not be very easy to determine exactly all the divisions from the alteration of the bulk of the contained fluid. And besides, as glass itself is dilated by heat, though in a less proportion than quicksilver, it is only the excess of the dilatation of the contained fluid above that of the glass that is observed; and therefore if different kinds of glass be differently affected by a given degree of heat, this will make a seeming difference in the dilatations of the quicksilver in the thermometers constructed in the Newtonian method, either by Reaumur's rule or De l'Isle's. Accordingly it has been found, that the quicksilver in De l'Isle's thermometers has stood at different degrees of the scale when immerged in thawing snow: having stood in some at 154°, while in others it has been at 156° or even 158°.

The thermometer at present used in France is called *Reaumur's*; but it is very different from the one originally invented by Reaumur in 1730, and described in the Memoirs of the Academy of Sciences. The one invented by Reaumur was filled with spirit of wine; and though its scale was divided by the author into 80 parts, of which 0 was the freezing point, and 80 the boiling water point, yet in fact 80 was only the boiling point of the spirit of wine that he employed, which, as Dr. Martine computes, corresponded with 180 of Fahrenheit. But the thermometer now in use in France is filled with mercury; and the boiling water point, which is at 80, corresponds with the 212th degree of Fahrenheit. The scale indeed commences at the freezing point, as the old one did. The new thermometer ought more properly to be called *De Luc's thermometer*, for it was first made by De Luc; and is in fact as different from Reaumur's as it is from Sir Isaac Newton's. When De Luc had fixed the scale, and finished an account of it, he showed the manuscript to M. De la Condamine. Condamine advised

him to change the number 80; remarking, that such was the inattention of philosophers, that they would probably confound it with Reaumur's. De Luc's modesty, as well as a predilection for the number 80, founded, as he thought, on philosophical reasons, made him decline following this advice. But he found by experience that the prediction of Condamine was too well founded.

The thermometer of Celsius, which is used in Sweden, has a scale of 100 degrees from the freezing to the boiling water point. This is, in fact, the *centigrade* thermometer.

These are the principal thermometers now used in Europe; and the temperatures indicated by any of them may be reduced into the corresponding degrees on any of the others by means of the following simple theorems; in which R signifies the degrees on the scale of Reaumur, F those of Fahrenheit, and S those of the Swedish thermometer.

1. To convert the degrees of Reaumur into those of Fahrenheit; $\frac{R \times 9}{4} + 32 = F$.

2. To convert the degrees of Fahrenheit into those of Reaumur; $\frac{(F - 32) \times 4}{9} = R$.

3. To convert the Swedish degrees into those of Fahrenheit; $\frac{S \times 9}{5} + 32 = F$.

4. To convert Fahrenheit's into Swedish; $\frac{(F - 32) \times 5}{9} = S$.

5. To convert Swedish degrees into those of Reaumur; $\frac{S \times 4}{5} = R$.

6. To convert Reaumur's degrees into Swedish; $\frac{R \times 5}{4} = S$.

To such readers as are unacquainted with the algebraic expression of arithmetical formulæ, it will be sufficient to express one or two of these in words to explain their use.—1. Multiply the degree of Reaumur by 9, divide the product by 4, and to the quotient add 32, the sum expresses the degree on the scale of Fahrenheit.—2. From the degree of Fahrenheit substract 32, multiply the remainder by 4, and divide the product by 9, the quotient is the degree according to the scale of Reaumur, &c.

As in meteorological observations it is necessary to attend to the greatest rise and fall of the thermometer, attempts have been made to construct a thermometer which might register the greatest degree of heat, or greatest degree of cold, which took place during the absence of the observer.

In 1782, Mr. Six proposed a self-registering thermometer.

It is properly a spirit of wine thermometer, though mercury is also employed for supporting an index. *ab* (fig. 10. pl. XXXVII.) is a thin tube of glass 16 inches long, and 5-16ths of an inch calibre: *cde* and *fgh* are smaller tubes, about 1-20th of an inch calibre. These three tubes are filled with highly rectified spirit of wine, except the space between *d* and *g*, which is filled with mercury. As the spirit of wine contracts or expands in the middle tube, the mercury falls or rises in the outside tubes. An index, made of thin wire with a knob, is placed on the surface, within each of these tubes, so light as to float upon it. *k* is a small glass tube 3-4ths of an inch long, hermetically sealed at each end, and inclosing a piece of steel wire nearly of its own length. At each end *l*, *m*, of this small tube, a short tube of black glass is fixed, of such a diameter as to pass freely up and down within either of the outside tubes of the thermometer *ce* or *fh*. From the upper end of the index is drawn a spring of glass to the fineness of a hair, and about 5-7ths of an inch long; which, being placed a little oblique, presses lightly against the inner surface of the tube, and prevents the index from descending when the mercury descends. These indexes being inserted one into each other of the outside tubes, it is easy to understand how they point out the greatest heat or cold that has happened in the observer's absence. When the spirit of wine in the middle tube expands, it presses down the mercury in the tube *hf*, and consequently raises it in the tube *ec*; consequently the index on the left hand tube is left behind and marks the greatest cold, and the index in the right hand tube rises and marks the greatest heat.

In 1790 a paper was presented to the Royal Society of Edinburgh, describing two thermometers, newly invented by Dr. John Rutherford of Middle Balilish; the one for registering the highest and the other for registering the lowest degree of heat to which the thermometer has risen or fallen during the absence of the observer. An account of them may be found in the third volume of the Transactions of the Society.

A new self-registering thermometer has more lately been invented by Mr. Keith of Ravelstone, which we consider as the most ingenious, simple, and perfect, of any which has hitherto appeared. Its simplicity is so great, that it requires only a very short description to make it intelligible. It is constituted, first, of a thin glass tube about fourteen inches long, and 3-4ths of an inch calibre, close or hermetically sealed at top. To the lower end, which is open, there is joined a crooked glass tube, seven inches long, and 4-10ths of an inch calibre, and open at its top, which, of course, is level with the middle of the first

tube. The former tube is filled with the strongest spirit of wine, and the latter tube with mercury. This is properly a spirit of wine thermometer, and the mercury is used merely to support a piece of ivory or glass, to which is affixed a wire for raising one index or depressing another, according as the mercury rises or falls. There is a small conical piece of ivory or glass, of such a weight as to float on the surface of the mercury. To the float is joined a wire called the *float-wire,* which reaches upwards, where it terminates in a knee bent at right angles. The float-wire, by means of an eye at its extremity, moves easily along a small vertical harpsichord wire. There are two indexes made of thin black oiled silk, which slide upwards or downwards with a force not more than two grains. The one placed above the knee points out the greatest rise, and the one placed below it points out the greatest fall, of the thermometer.

When the instrument is to be prepared for an observation, both indexes are to be brought close to the knee. It is evident, that when the mercury rises, the float and float-wire, which can be moved with the smallest force, will be pushed upwards till the mercury becomes stationary. As the knee of the float-wire moves upwards it will carry along with it the upper index. When the mercury again subsides, it leaves the index at the highest point to which it was raised, for it will not descend by its own weight; as the mercury falls, the float-wire does the same; it therefore brings along with it the lower index, and continues to depress it till it again becomes stationary or ascends in the tube; in which case it leaves the lower index behind it as it had formerly left the upper. The scale to which the indexes point is placed parallel to the slender harpsichord wire. That the scale and indexes may not be injured by the wind and rain, a cylindrical glass cover, close at top, and made so as exactly to fit, is placed over it.

The ingenious inventor has another improvement, which, if upon trial it be found to answer, will make this thermometer as perfect as can be desired, provided there do not arise some errors from the variable pressure of the atmosphere. He proposes to adapt clock-work to this thermometer, in such a way as to register with the utmost precision the degrees of heat and cold for every month, day, and minute, in the year. An account of this latter improvement may be seen in Nicholson's Journal, vol. iii. 4to. series, or Edin. Transac. vol. iv.

The common contrivance for a self-registering thermometer, now sold in most of the London shops, consists simply of two thermometers, one mercurial and the other of alcohol (fig. 4. pl. XXXI.) having their stems horizontal: the former has for

its index a small bit of magnetical steel wire, and the latter a minute thread of glass, having its two ends formed into small knobs by fusion in the flame of a candle.

The magnetical bit of wire lies in the vacant space of the mercurial thermometer, and is pushed forward by the mercury whenever the temperature rises, and pushes that fluid against it: but when the temperature falls and the fluid retires, this index is left behind, and consequently shows the maximum. The other index, or bit of glass, lies in the tube of the spirit thermometer immersed in the alcohol, and when the spirit retires by depression of temperature, the index is carried along with it in apparent contact with its interior surface: but on increase of temperature the spirit goes forward and leaves the index, which therefore shows the minimum of temperature since it was set. As these indexes merely lie in the tubes, their resistance to motion is altogether inconsiderable. The steel index is brought to the mercury by applying a magnet on the outside of the tube, and the other is duly placed at the end of the column of alcohol by inclining the whole instrument.

Mr. Nicholson explains the operation of this instrument thus: "When the surface of the column of spirit is viewed by a magnifier, it is seen to have the form of a concave hemisphere, which shows that the liquid is attracted by the glass. The glass in that place is consequently attracted in the opposite direction by a force equal to that which is so employed in maintaining that concave figure; and if it were at liberty to move, it would be drawn back till the flat surface was restored. Let us suppose a small stick or piece of glass to be loose within the tube, and to protrude into the vacant space beyond the surface of the alcohol. The fluid will be attracted also by this glass, and form a concave between its surface and that of the bore of the tube. But the small interior piece being quite at liberty to move, will be drawn towards the spirit so long as the attractive force possesses any activity; that is, so long as any additional fluid hangs round the glass; or, in other words, until the end of the stick of glass is even with the surface. Whence it is seen that the small piece of glass will be resisted, in any action that may tend to protrude it beyond the surface of the fluid; and if this resistance be greater than the force required to slide it along in the tube (as in fact it is), the piece must be slided along as the alcohol contracts; so as always to keep the piece within the fluid. And this fact is accordingly observed to take place." (Nich. Jour. N. S. No. 47).

Mr. Professor Leslie, well known for his ingenious "Experimental Enquiry into the Nature and Propagation of Heat," and other works of science, has invented a *Differential Thermo-*

meter for the measurement of minute variations of temperature. It consists of two tubes, each terminating in a small bulb of the same dimensions, joined by the blow-pipe, and bent in the form of a U, a small portion of dark coloured liquor having previously been introduced into one of the balls. After many trials, the fluid best adapted to the purpose was found to be a solution of carmine in concentrated sulphuric acid. By managing the included air with the heat of the hand, this red liquor is made to stand at the required point of the opposite tube. This is the zero of a scale fastened to that tube, and divided into equal parts above and below that point. The instrument is then fixed on a stand. It is manifest that when the liquor is at rest, or points at zero, the column is pressed in opposite directions by two portions of air equal in elasticity, and containing equal quantities of caloric. Whatever heat, then, may be applied to the whole instrument, provided both bulbs receive it in the same degree, the liquor must remain at rest. But if the one ball receives the slightest excess of temperature, the air which it contains will be proportionally expanded, and will push the liquid against the air in the other bulb with a force, varying as the difference between the temperatures of those two portions of air: thus the equilibrium will be destroyed, and the fluid will rise in the opposite tube. The degrees of the scale through which it passes will mark the successive augmentations in the temperature of the ball, which is exposed to the greatest heat. So that this instrument is a balance of extreme delicacy for comparing the temperatures of its two scales.

It is a small variation from this thermometer that constitutes Mr. Leslie's *Photometer*. Those who wish to learn more of the nature of this latter mentioned instrument may consult Mr. Leslie's Treatise on Heat, Nicholson's Journal, vol. iii. 4to. or some acute remarks in the Edinburgh Review, No. 13.

When thermometers are devised to measure very great degrees of heat, they are usually called by another name. See PYROMETER.

The thermometer and barometer together are very useful in determining the altitudes of mountains, &c. according to the rules delivered in our first volume, book v. For this purpose they are fixed in such a frame as to be conveniently portable. (See BAROMETER). Other portable instruments by Mr. M'Guire and M. Humboldt, which we omitted mentioning in that article, are described, the former in the Transactions of the Royal Irish Academy for 1787, the latter in Journal de Physique, an 7, or Tilloch's Philosophical Magazine, No. 15.

Supplement to the article Thermometer.

Immediately connected with the construction and improvement of thermometers are M. Biot's "*Researches into the laws of the dilatations of liquids at all temperatures;*" of which, therefore, I shall present, in this place, a translation with slight abridgment*.

The knowledge of the laws observed in the dilatation of liquids is necessary in an infinity of chemical and physical inquiries. We require the dilatations of water, in order to reduce the specific gravities observed in that liquid to comparable terms. We require those of alcohol to determine its density at different temperatures, or to observe the thermometers in which that substance is employed. Or, if we would attempt theoretically to compare the dilatability of different liquids respectively, and to connect their more or less rapid progress, with their tendency more or less near to ebullition and to solidification, we cannot accomplish it generally, or obtain any precise ideas on this point, without expressing the dilatations by formulæ which shall represent them at all temperatures, and at the same time render evident the particularities of each of the liquids it is wished to examine.

Such is the object M. Biot proposes to himself. He shows that for all liquids whose dilatations have hitherto been observed, the general progress of each respective dilatation may be represented at all temperatures by an expression of this form:

$$\delta_t = at + bt^2 + ct^3,$$

in which t denotes the temperature in degrees of the mercurial thermometer, and a, b, c, constant coefficients which depend on the nature of the liquid. He here supposes that δ_t is the true dilatation for the unit of volume reckoned from the temperature of thawing ice; but it is easy to conclude, hence, that the apparent dilatation follows similar laws: for, representing this latter by Δ_t and denoting by κ the cubic dilatation of the matter of the vessel that contains the observed liquid †, we have

$$\Delta_t = \delta_t - \kappa t;$$

neglecting here the square of the co-efficient κ, which is almost

* The paper that contains these researches was read to the Society of Arcueil, August 8th, 1813. It is printed in France; but the work in which it appeared had not been published in March 1815. I have to acknowledge my obligations to M. *Biot*, for transmitting these investigations to me, through the medium of my friend M. *Hachette*, (Professor of Mathematics in the Polytechnic School), for the purpose of insertion in this work.

† M. Biot means by cubic dilatation the triple of the linear dilatation.

always allowable, since the dilatation of solid bodies is extremely small.

Let it be supposed that the primitive volume of the liquid being 1 when $t=0^\circ$, occupies at $+t$ degrees a number of divisions x in the vessel whose cubic dilatation is K. This number of divisions will indicate a greater capacity than when t was nothing. It will answer to the capacity $x\,(1+Kt+\frac{1}{3}K^2t^2)$ limiting the expression to the square of K; and as by supposition it is equal to $1+\delta_t$, since δ_t is the true dilatation for the unit of volume, we shall have the equation

$$x(1+Kt+\tfrac{1}{3}K^2t^2)=1+\delta_t;\ \text{which gives}$$

$$x=\frac{1+\delta_t}{1+Kt+\frac{1}{3}K^2t^2}=1+\frac{\delta_t-Kt-\frac{1}{3}K^2t^2}{1+Kt+\frac{1}{3}K^2t^2}.$$

The first term of this expression is the primitive volume at 0°; the second is the apparent dilatation Δ_t: we have, therefore,

$$\Delta t=\frac{\delta_t-Kt-\frac{1}{3}K^2t^2}{1+Kt+\frac{1}{3}K^2t^2}$$

The term affected by $\frac{1}{3}K^2$ is absolutely insensible in the most exact observations on the dilatations of liquids made with glass vessels, between the temperatures of -15° and $+100^\circ$ (centigrade). Neglecting it, therefore, we have simply $\Delta t=\frac{\delta t-Kt}{1+Kt}$, a value which, by neglecting the square of K and the product of K by δ_t, reduces to $\Delta_t=\delta_t-Kt$, as we have assumed above.

Now, to establish the preceding law, and determine the coefficients a, b, c, relatively to different liquids, M. Biot employed the results of a series of experiments, made, with much care, by De Luc*, on the dilatation of *nine* different liquids with which he had constructed thermometers, regulating them from the temperatures of melting ice, and boiling water; marking 0° at the first point, 80° at the second, and dividing the interval into 80 equal parts. These liquids were, 1. Mercury. 2. Oil of olives. 3. Essential oil of camomile. 4. Essential oil of thyme. 5. Water saturated with muriat of soda. 6. Alcohol highly rectified. 7. Alcohol and water in equal parts. 8. Alcohol one part, water three. 9. Water.

* Researches on the Modifications of the Atmosphere, vol. i.

Comparative Indications of Nine Thermometers made of different Liquids.

Reaumur's scale. / Mercury.	Oil of olives.	Essential oil of camomile.	Essential oil of thyme.	Water saturated with muriat of soda.	Highly rectified alcohol.	One part alcohol, one water.	One part alcohol, three water.	Water.
80	80·0	80·0	80·0	80·0	80·0	80·0	80·0	80·0
75	74·6	74·7	74·3	74·1	73·8	73·2	71·6	71·0
70	69·4	69·5	68·8	68·4	67·8	66·7	62·9	62·0
65	64·4	64·3	63·3	62·6	61·9	60·6	55.2	53·5
60	59·3	59·1	58·3	57·1	56·2	54·8	47·7	45·8
55	54·2	53·9	53·3	51·7	50·7	49·1	40·6	38·5
50	49·2	48·8	48·3	46·6	45·3	43·6	34·4	32·0
45	44·0	43·6	43·4	41·2	40·2	38·4	28·4	26·1
40	39·2	38·6	38·4	36·3	35·1	33·3	23·0	20·5
35	34·2	33·6	33·5	31·3	30·3	28·4	18·0	15·9
30	29·3	28·7	28·6	26·5	25·6	23·9	13·5	11·2
25	24·3	23·8	23·8	21·9	21·0	19·4	9·4	7·3
20	19·3	18·9	19·0	17·3	16·5	15·3	6·1	4·1
15	14·4	14·1	14·2	12·8	12·2	11·1	3·4	1·6
10	9·5	9·3	9·4	8·4	7·9	7·1	1·5	0·2
5	4·7	4·6	4·7	4·2	3·9	3·4	1·0	−0·4
0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
−5				−4·1	−3·9			
−10				−8·0	−7·7			

If we express by D_T the number of degrees indicated by each of these thermometers, on its own scale, when T is the number indicated by the mercurial thermometer divided into 80 parts, all the experiments of De Luc may be represented by the general formula

$$D_T = AT + BT^2 + CT^3;$$

A, B, C, being arbitrary constant quantities, differing in the different liquids: and of which the absolute values, as inferred by M. Biot, from De Luc's experiments, are presented in the following table.

Nature of the liquids.	Values of the co-efficients.		
	A	B	C
Mercury - -	+1·000000	+0·0000000	+0·000000000
Oil of olives -	+0·950667	+0·0007500	−0·000001667
Ess. oil of camom.	+0·920442	+0·0013056	−0·000003889
Essent. oil of thyme	+0·949335	−0·0001667	+0·000010000
Water satur. with muriat of soda	+0·820006	+0·0020275	+0·000002775
Alcohol highly rect.	+0·784000	+0·0020800	+0·000007750
1 Alcohol, 1 water	+0·705333	+0·0027500	+0·000011667
1 Alcohol, 3 water	+0·010333	+0·0155277	−0·000039444
Pure water - -	−0·160000	+0·0185000	−0·000050000

To prove the correspondence of these results with the observations, M. Biot has computed the values of D_T by the formula for each of these liquids for every 10°, and compared them with the numbers given by De Luc's observations.

1. Thus, computing the thermometer of *oil of olives* from the formula

$$D_T = 0{\cdot}950667T + 0{\cdot}00075T^2 - 0{\cdot}000001667T^3,$$

we have the following comparative table.

Kind of liquid.	Degrees of mercurial Thermo.	Degree of Thermometer, Olive oil.		
		Computed.	Observed.	Excess of observations.
Olive oil.	80	80·00	80·0	0·00
	70	69·64	69·4	−0·24
	60	59·37	59·3	−0·07
	50	49·20	49·2	0·00
	40	39·12	39·2	+0·08
	30	29·15	29·3	+0·15
	20	19·30	19·3	0·00
	10	9·58	9·5	−0·08
	0	0·00	0·0	0·00

Here the greatest variation between the observation and the computation is less than one fourth of a degree; and nearly all the rest are exceedingly minute.

M. De Luc put the oil of olive thermometer several times in a refrigerating mixture which caused the mercurial thermometer to descend to $-14°$; and he relates that the oil thermometer remained nearly at that degree so long as the oil was not congealed. This result agrees with the preceding formula; for if we suppose $T = -14°$, the formula gives $D_T = -13°{\cdot}21$.

But when the oil began to congeal, the olive oil thermometer fell, all at once, much lower than the mercurial thermometer; the oil, indeed, retired entirely within the ball. It will be seen that it was the congelation which produced this sudden depression: for, when it has taken place, if the temperature be raised, the mercurial thermometer will rise immediately, but the oil thermometer will remain at its extreme point of depression, during an interval sometimes considerable, being, without doubt, that which the oil would require to become uncongealed. But having once resumed its liquid state, it will soon regain its relative position as to the mercurial thermometer, and manifest its accustomed progress. De Luc supposed that it was the privation of air which enabled the oil to undergo, without congealing, a degree of cold which would have caused its congelation in the open air. But it appears from the experiments of Sir Charles Blagden, that neither the exclusion of the air, nor rest, are absolutely necessary to the production of that effect, though they may contribute to it.

We may learn from these phenomena, 1. That oil of olives may, in certain circumstances, as well as water, be depressed to a temperature far lower than its ordinary degree of congelation, without ceasing to be liquid. 2. That it contracts in congealing, as mercury does, which is evident of itself, as the parts congealed retire to the bottom of the vessel. 3. That, down to the very moment in which it becomes solid, it retains exactly or very nearly the same law of dilatation: this appears also to obtain with respect to mercury, as we conclude from the discussion of Mr. Cavendish relative to the experiments of Hutchins at Hudson's Bay.

Hence we see that olive oil, in cooling to any degree whatever, cannot, like water, have an apparent *maximum* of condensation, at least in glass tubes. This, also, is shown by our formula: for this maximum would answer to the case in which we should have

$$\frac{\dot{D}_T}{\dot{T}} = 0; \text{ which gives}$$

$$0 = 0{\cdot}950667 + 0{\cdot}0015T - 0{\cdot}000005T^2;$$

an equation of which the roots are

$$T' = -311°{\cdot}1; \quad T'' = +611°{\cdot}1.$$

This indicates that if the oil could remain liquid in the thermometer at these temperatures, and if it continued to dilate according to the same law, it would have an apparent maximum of *condensation* at 311°.1 below zero, and a maximum of *dilatation* at 611°.1 above it. But these limits are far too remote from our observations, to allow of our safely extending to them the consequences of the formula. All that can hence be concluded is, that olive oil, so long as it remains liquid, continues to contract by cooling, and that it will even congeal without expanding; which is conformable to the observations.

2. For the *essential oil of camomile*, the theorem is

$$D_T = 0{\cdot}9204416T + 0{\cdot}0013056T^2 - 0{\cdot}000003889T^3$$

The comparison of the results of this formula with obsrvations gives the greatest deviation at 40°; but even there it is only $-0°06$; in most temperatures below 30° or above 45° it is scarcely perceptible. So that practically this theorem may be considered as exact as observation itself. It appears, also, that *this* oil has not a maximum of condensation; for the equation of such maximum is

$$0 = 0{\cdot}9204416 + 0{\cdot}002612T - 0{\cdot}000011667T^2,$$

the roots of which are $T' = -189°.$; $T'' = +413°$. Both these values are far too remote from our experiments to be regarded as applicable.

3. Proceeding next to the *essential oil of thyme*, we have the formula

$$D_T = 0{\cdot}949336T - 0{\cdot}0001667T^2 + 0{\cdot}00001T^3.$$

The comparison with experiment furnishes a very satisfactory correspondence: from 60° to 70° the differences between computation and observation are nearly a quarter of a degree; at most other temperatures the differences are imperceptible. Here, again, there is no maximum of condensation: for the equation which would give the maximum is

$$0 = 0{\cdot}949336 - 0{\cdot}0003334T + 0{\cdot}00003T^2,$$

the two roots of which are imaginary. Thus, this oil, like the preceding, may become congealed without dilating.

4. For *water saturated with muriat of soda*, the theorem is

$$D_T = 0{\cdot}820006T + 0{\cdot}0020275T^2 + 0{\cdot}000002775T^3.$$

The correspondence of observations with this theorem is nearly as great as can be desired. In only two cases between 80° and $-10°$, does the difference exceed a tenth of a degree; and in the majority of instances the difference did not exceed 0·01 of a degree. The temperature was carried below zero by

means of freezing mixtures. This solution, again, congeals without dilating. For the equation of the maximum is

$$0 = 0{\cdot}820006 + 0{\cdot}004055\text{T} + 0{\cdot}000008325\text{T}^2,$$

of which the two roots are imaginary. Thus the muriat of soda, on combining with the water to saturation, loses its property of dilating before it becomes solid. It would be interesting to verify this result by experiment. For, although it seems here founded on a very strong analogy, since the law of the dilatation and contraction is maintained very rigorously down to $-10°$ Reaumur; yet it must only be spoken of as being highly probable. But to make the experiment well, it will be requisite that the thermometer formed of the solution be most carefully freed from air, and that the refrigeration be carried on slowly, in order that the solution may be kept fluid even a little below the usual degree of its congelation.

Sir Charles Blagden has made an observation of this kind, which is related in his interesting memoir on "The effect of various substances in lowering the point of congelation in water*;" but the solution which he employed was not saturated; it contained 4·8 of water to 1 of salt. Consequently, its point of congelation ought to be at $-10°{\cdot}37$ according to the law which Sir Charles has found. This solution continued to contract till it was cooled to $-6°{\cdot}67$ (17° Fahr.) but had sensibly expanded by the time it was cooled to $-7°{\cdot}55$ (15° Fahr.) These limits are far elevated above the temperature $-10°$ to which De Luc has carried the saturated solution which formed his thermometer, without its exhibiting any sign which announced a dilatation: consequently, the experiment of Blagden cannot invalidate the law which we have found for the saturated solution employed by De Luc. It would be very natural that a certain proportion of salt would deprive the water of its property of dilating before congelation, and that a less proportion would not produce the same effect. This is precisely what obtains in mixtures of water and alcohol, as will soon be seen.

5. We now pass to *highly rectified alcohol*, for which the formula is

$$\text{D}_\text{T} = 0{\cdot}784\text{T} + 0.00208\text{T}^2 + 0{\cdot}00000775\text{T}^3.$$

The comparison of the results of the theorem with those of experiment gives a difference of 0°·16 at the temperature of 10°. At no other temperature subjected to the comparison does it amount to half this, and in nearly half the cases it was imperceptible. Here, again, the law of the dilatation does not indi-

* Phil. Trans. vol. lxxviii. New Abridgement, vol. xvi. p. 472.

cate any retrogradation, for the condition of the maximum of D_T will be

$$0 = 0{\cdot}784 + 0{\cdot}00416T + 0{\cdot}00002325T^2,$$

the two roots of which are imaginary.

The value of D_T given by our formula will be very convenient for the comparison of thermometers of alcohol with mercurial thermometers. It will be seen that this is often indispensable; for there is much difference between the two thermometers, when they are both regulated to the terms of the freezing and boiling points. The difference becomes less when the thermometer of alcohol is regulated to the mercurial one at lower temperatures. If we put $T = (T) + T'$, and determine (T) in such manner as to cause the square of T' to disappear from D_T, we shall find $(T) = -89^0{\cdot}463$ R; and then the transformed value of D_T will become

$$D_T = -58^0{\cdot}981 + 1{\cdot}34218T' + 0{\cdot}00000775T'^3.$$

The thermometer of alcohol will, therefore, mark $-58^0{\cdot}981$ on its own scale, when T' will be nothing, that is, when the mercurial thermometer stands at $89^0{\cdot}463$ below zero. Proceeding from this term to 80° either above or below, the progress of the two thermometers will be nearly proportional; for the term containing T'^3 which alone affects the exactness of the proportionality, cannot reach 4 degrees in the extreme case where we make $T' = \pm 80°$. Such is, therefore, the greatest correspondence which can ever exist between the alcohol and mercurial thermometers, supposed indefinitely prolonged below zero.

6. Let us next consider the *mixtures of water and alcohol.* And first when the proportion of water is small, the affinity of alcohol for it long preserves its liquidity and opposes its retrogradation. This is proved by observation upon the thermometer constituted of equal parts of alcohol and water. The formula in that case is

$$D_T = 0{\cdot}705333T + 0{\cdot}00275T^2 + 0{\cdot}000011667T^3:$$

and the comparison with observations proves that the law of the dilatation is very well represented by this formula. The proportion of water is not yet sufficient to communicate to the alcohol its retrograde property: for the equation which gives the maximum of D_T is

$$0 = 0{\cdot}705333 + 0{\cdot}0055T + 0{\cdot}000035T^2,$$

and its two roots are imaginary.

7. But on augmenting the water the influence of that liquid

will become perceptible. Thus, taking the thermometer made with *one* part of alcohol and *three* of water, the formula becomes

$$D_T = 0{\cdot}010333T + 0{\cdot}0155277T^2 - 0{\cdot}000039444T^3.$$

Here the term proportional to the temperatures is almost insensible; only giving 0°·8 at the temperature of 80°. This is occasioned by the influence of the water; for in pure water this term is negative, as will soon be seen. The comparison of the experiments with computation from the formula is as follows.

Nature of the liquid.	Degrees on mercur. thermom.	Degrees therm. made with the mixture.		
		Computed.	Observed.	Excess of observ.
	80	80·00	80·0	0·00
Mixture of	70	63·24	62·9	— 0·34
1 part	60	47·99	47·7	— 0·29
alcohol	50	34·40	34·4	0·00
with	40	22·72	23·0	+ 0·28
3 parts	30	13·21	13·5	+ 0·29
water.	20	6·10	6·1	0·00
	10	1·61	1·5	— 0·11
	0	0·00	0·0	0·00

Here the law of the dilatation is very different from that which obtained in pure alchohol, and the difference of the two thermometers is also much more considerable. For ascertaining the maximum of condensation, we have the equation

$$0 = 0{\cdot}010333 + 0{\cdot}0310554T - 0{\cdot}000118333T^2,$$

of which the roots are

$$T' = -0^\circ{\cdot}333, \quad T'' = +263^\circ.$$

The first alone is admissible; it gives a maximum of condensation at $\frac{1}{3}$ of a degree of Reaumur below zero. Substituting this value of T' in the equation for D_T, we shall find $D_T = -0^\circ{\cdot}0017$, that is to say, at the instant of this maximum of condensation the thermometer of the mixture ought to be as to sense, at 0 on its own scale. This maximum is indicated by the slow dilatation of the mixture, which, according to observation, was only 0°·1 on its own scale when the mercurial thermometer was at + 5°. According to the formula it should then have been at + 0°·4: the error is of the order of those which may be expected from the deduction of the formula and the nature of observation.

8. Lastly, we shall proceed to examine the law of the dilatation in the thermometer made of *distilled water*, for which the theorem is

$$D_T = -0.16T + 0{\cdot}0185T^2 - 0{\cdot}0000T^3.$$

Here the term proportional to the temperature is *negative;* and among the liquids which we have examined, water is the only one which presents that peculiarity. Hence it is natural to infer that its dilatations will differ much from those of mercury; and this is clearly shown by the following table.

Nature of the liquid.	Degrees of mercur. thermom.	Degrees of water thermom.		
		Computed.	Observed	Excess of observa.
Distilled water.	80	80·0	80·0	0·0
	70	62·3	62·0	— 0·3
	60	46·2	45·8	— 0·4
	50	32·0	32·0	0·0
	40	20·0	20·5	+ 0·5
	30	10·5	11·2	+ 0·7
	20	3·8	4·1	+ 0·3
	10	0·2	0·2	0·0
	5	— 0·343	— 0·4	— 0·057
	0	0·0	0·0	0·0

This thermometer is certainly the most irregular of all; a circumstance peculiar to water, as De Luc has frequently remarked in his work. Yet we see that the observations oscillate about the formula within very narrow limits; the discrepancies being, indeed, such as are fairly attributable to the observations.

Here we have a maximum of condensation, the equation which determines it being

$$0 = -0{\cdot}16 + 0.037T - 0{\cdot}00015T^2,$$

whose roots are $T' = +4{\cdot}402°$ and $T'' = +251°$.
The first is that which renders D_T a *minimum*, and which consequently indicates a *maximum* of condensation. De Luc says that this maximum appeared to him to answer nearly to the temperature of $+4°$, which differs very little from the computation. He remarks, also, that at the moment of this phenomenon, the thermometer of water stood at about $\frac{1}{2}$ a degree below zero on its own scale. Our formula gives $-0^0.35$.

Let it be remarked that this *maximum* is only *apparent,* and that it must receive a correction to exhibit the real maximum. Let it be recollected, farther, that we here employ distilled water, free from air, and that common water, which contains air, probably dilates according to rather different proportions.

9. M. Biot, previously to deducing from these results the true and absolute dilatations of the liquids observed by De Luc, remarks, that the thermometrical observations on which the preceding deductions are founded may not perhaps be exempt from slight inaccuracies. In M. De Luc's work he treats much at large on the construction of the thermometer, and speaks only of the care which should be taken in immersing at once the ball and the liquid column in the temperature which he would communicate to it. The same thing should be regarded in observing the intermediate temperatures between the fixed points. If these precautions have been neglected by De Luc, which, in truth, is scarcely probable, all the numbers observed by that philosopher will be affected by a small error, equal to the dilatation of the portion of liquid contained in the tube of his thermometers at each of the temperatures observed. Hence it would be interesting to have these results confirmed, by a repetition of the experiments.

10. Let us now proceed to deduce the true and absolute dilatations: which is very easy. To fix and graduate the thermometers De Luc put them successively in the temperatures of melting ice and boiling water; marking in each case the upper extremity of the liquid column, and dividing the interval into 80 equal parts. Consequently, the absolute and apparent dilatation of the liquid employed being represented together by D, that dilatation will determine the extent of 80°; and thence, knowing D_T, that is to say, the number of degrees of the same thermometer corresponding to the temperature T, we may easily deduce the apparent dilatation Δ_T; for we have obviously

$$\Delta_T = \frac{D}{80} D_T.$$

But, calling δ_T the true and absolute dilatation of a liquid, that is, the dilatation which would be observed in a vessel not dilatable, we have seen that it may be computed from the apparent dilatation, and that we have in general

$$\delta_T = KT + (1 + KT)\,\Delta_T;$$

K being the cubic dilatation of the matter of the vessel in which the apparent dilatation Δ_T is observed. Putting, therefore, here, for Δ_T its value in terms of D_T it will become

$$\delta_T = KT + D\,\frac{1+KT}{80}\,D;$$

then, substituting for D, the general expression $\text{AT} + \text{BT}^2 + \text{CT}^3$, which has been verified, we have

$$\delta_{\text{T}} = \text{KT} + \text{D}\,\frac{(\text{AT} + \text{BT}^2 + \text{CT}^3)\cdot(1 + \text{KT})}{80},$$

which, by actual multiplication, becomes

$$\delta_{\text{T}} = (\text{K} + \frac{\text{DA}}{80}\text{T}) + \frac{\text{B} + \text{AK}}{80}\,\text{DT}^2 + \frac{\text{C} + \text{BK}}{80}\,\text{DT}^3 + \frac{\text{KCD}}{80}\,\text{T}^4.$$

The term that includes T^4 may be always regarded as insensible. For water it would only give $\frac{32}{10000000}$ of the primitive volume even when $\text{T} = 80^\circ$. Thus, neglecting this term, when the total dilatation D is known for any liquid, we must substitute its value in this formula, and making

$$a = \text{K} + \frac{\text{DA}}{80}, \ldots b = \text{D}\,\frac{\text{B} + \text{AK}}{80}, \ldots c = \text{D}\,\frac{\text{C} + \text{BK}}{80},$$

we shall have, for any other temperature, the true and absolute dilatation δ_{T} by the formula

$$\delta_{\text{T}} = a\text{T} + b\text{T}^2 + c\text{T}^3,$$

which is that which was announced at the commencement of these inquiries. But, if the experiments which we employ are extremely accurate, the term proportional to the fourth power of the temperatures may perhaps be rendered perceptible; and in that case it would be necessary to introduce a term of that order in the computation of D_{T} from the observations. Let it be remarked also, that these formulæ being expressed in degrees on Reaumur, the cubic dilatation K of the matter of which the vessel is constituted must always be taken in reference to those degrees.

11. All De Luc's experiments were made with thermometer tubes of glass. From the experiments of Lavoisier and Laplace it appears that the cubic dilatation of glass employed for this purpose is 0·0000262716 for each degree of the centesimal thermometer. Multiplying this by $\frac{10}{8}$ or adding to it $\frac{1}{4}$ of its value, we shall have the cubic dilatation corresponding to a degree on Reaumur's scale, namely, $\text{K} = 0{\cdot}00003284$.

All is reduced, therefore, to the determining by experiment the total and apparent dilatation D. Unfortunately, there are no liquids of which it can at present be said that this is precisely known. In this uncertainty let us investigate the means of computing it for water and alcohol, from the experiments of Gilpin and Blagden, having regard to the dilatations of the vessels. In truth, those philosophers have only determined the weights from 0° to 30°·2 R.; but, as they appear to have been made with very great care, their precision may compensate for what they want in extent. Besides which, there are easy

means of trying our formulæ, and deducing values which may one day be verified by direct experiments.

12. We shall commence with *alcohol*. By comparing the weights of the same volume of this liquid ascertained by Gilpin and Blagden at 30°, 35°, and 40° of Fahrenheit, M. Biot has deduced by interpolation the weight of the same volume at 32°, which answers to 0° upon Reaumur's scale. Then comparing that result with the weights observed at 50°, 70°, 95°, and 100° of Fahrenheit, he has deduced the relation of the volumes at those different temperatures, assuming for unit the primitive volume at 32°, or at the temperature of melting ice. Thus he obtained the following results:

Degrees on mercurial thermometer.		Volume of alcohol observed.	Dilatation from the temperature of melting ice.
32° F or	0°·0 R	1·000000	0·000000
50	8 ·00	1·010003	0·010003
70	16·89	1·021750	0·021750
95	28 ·00	1·037369	0·037369
100	30 ·22	1·040525	0·040525

To deduce from these results the total dilatation D from 0° to 80° R, M. Biot employs the two last observations, and considers them as given values of δ_T. Then in the equation

$$\delta_T = KT + D\,\frac{(AT + BT^2 + CT^3)(1 + KT)}{80},$$

all is known except D; whence that quantity may readily be deduced. First, computing D_T and KT, there are found

$T = 28{\cdot}000;\ AT + BT^2 + CT^3 = 22{\cdot}753;\ KT = 0.00091952:$
$T = 30{\cdot}222;\ AT + BT^2 + CT^3 = 25{\cdot}808;\ KT = 0{\cdot}00099248:$

then from the observations we have

$$T = 28{\cdot}000;\ \delta_T = 0{\cdot}037369;\ \delta_T - KT, = 0{\cdot}036449;\ \frac{\delta_T - KT}{1 + KT} = 0.$$

$$T = 30{\cdot}222;\ \delta_T = 0{\cdot}040525;\ \delta_T - KT = 0{\cdot}039533;\ \frac{\delta_T - KT}{1 + KT} = 0.$$

Substituting these values in the formula, we shall have two equations, viz.

$$0{\cdot}036416 = \frac{23{\cdot}753}{80}D, \text{ and } 0{\cdot}039494 = \frac{25{\cdot}808}{80}D.$$

From the first, $D = 0122649$; from the second, $D = 0{\cdot}122424$.

These values differ only by 0·0002 of the primitive volume at 0°: taking, therefore, the mean, we have

$$D = 0{\cdot}122536.$$

which is the *apparent* dilatation of the alcohol in glass from 0° to 80° R. To obtain the *true* dilatation, recourse must be had to the formula

$$\delta_T = KT + (1 + KT)\,\Delta_T,$$

which, when $T = 80°$, becomes

$$\delta_{80} = 80K + (1 + 80K)\,D.$$

Substituting here for D and K the values already obtained, their results for highly rectified alcohol

$$\delta_{80} = 0{\cdot}1254852,$$

or nearly one-eighth. This is the true dilatation of alcohol from 0° to 80° R.

M. Biot knew of no other indication on this subject than that of Nollet, who, in his "*Leçons de Physique*," tom. iv. p. 379, says that alcohol is dilatedby 0·087 while passing from the temperature of congelation to that of boiling water. M. Biot shows the reasons of the want of correspondence in the results; and proceeds to compare his deductions with those of Sir Charles Blagden and Mr. Gilpin. In order to this, he computes the values of the true dilatation δ_T, for different temperatures comprised within the range of their experiments, by means of the formula

$$\delta_T = KT + \frac{D}{80}(AT + BT^2 + CT^3)(1 + KT).$$

Thus he obtains the following comparisons.

Degrees of the mercurial thermometer.		Corresponding degrees of alcohol thermom. computed.	True dilatation from the temperature of melting ice.		
			Computed.	Observed.	Excess of observa.
32° F. or	0° R.	0·000	0·00000	0·00000	0·00000
50	8.00	6·409	0·01008	0·01000	— 0·00008
70	16·89	13·939	0·02191	0·02175	— 0·00016
95	28·00	23·753	0·03733	0·03737	+ 0·00004
100	30·22	25·808	0·04056	0·04053	— 0·00003

The correspondence of these results is quite as perfect as could be hoped for; and the deviations of the formula from the observations may be as naturally ascribed to the latter as to the former. Hence, reducing the coefficients of δ_T and Δ_T into numbers, we shall have the following results for any temperature, T, whatever, expressed by the mercurial thermometer in degrees of Reaumur.

I. Degrees of the thermometer of alcohol on its own scale,

$$D_T = 0{\cdot}784T + 0{\cdot}00208T^2 + 0{\cdot}00000775T^3.$$

II. Apparent dilatation from 0° in glass tubes,

$$\Delta_T = 0.0020085T + 0.0000318593T^2 + 0{\cdot}00000001187T^3.$$

III. True dilatation,

$$\delta_T = 0{\cdot}00123369T + 0{\cdot}0000032253T^2 + 0{\cdot}00000001198T^3.$$

In this expression for the true dilatation the term containing T^4, whose coefficient is 4 preceded by 12 ciphers between it and the decimal point, is suppressed. The omission will only occasion an error of 0.00002 in a dilatation of 80°; and the observations never reach this precision. It must not be forgotten that these formulæ apply only to alcohol *highly rectified*; for we have seen that the dilatations of this liquid follow a different law when it contains a large portion of water. By means of these formulæ thermometers of alcohol or of mercury may be employed indifferently.

13. M. Biot institutes a similar calculus for *water*, proceeding here, also, from the experiments of Gilpin and Blagden, at the temperatures before specified. After tabulating his results as in the case of alcohol, he again employs the observations at 95° and 100° F, or 28° and 30°·22 R. He then recurs to the formula

$$\delta_T = KT + \frac{D(1+KT)}{80} D_T.$$

There result, from the computation,

$$T = 28{\cdot}000;\ D_T = 8{\cdot}9264;\ KT = 0{\cdot}000919;$$
$$T = 30{\cdot}222;\ D_T = 10{\cdot}6818;\ KT = 0{\cdot}000902.$$

Then from the observations,

$$28{\cdot}000;\ \delta_T = 0{\cdot}005829;\ \delta_T - KT = 0{\cdot}004910;\ \frac{\delta_T - KT}{1 + KT} = 0{\cdot}004050:$$

$$T = 30{\cdot}222;\ \delta_T = 0{\cdot}0068409;\ \delta_T - KT = 0{\cdot}0058485;\ \frac{\delta_T - KT}{1 + KT} = 0{\cdot}0058427.$$

Substituting these values in the formula, they give respectively the equations,

$$0{\cdot}004905 = \frac{8{\cdot}9264}{80} D, \text{ and } 0{\cdot}0058427 = \frac{10{\cdot}6818}{80} D.$$

It is obvious that, here, the minuteness of D_T renders the determination of D far less favourable than with respect to alcohol; so that it would have been preferable if we could have employed experiments made at a higher temperature. Yet the extreme care of the observers in great measure compensates for this disadvantage; and thus the two values of D deduced from these equations agree very well together. They are

$$D = 0{\cdot}0439595, \text{ and } D = 0{\cdot}0437582.$$

The difference between these is only 0·0002 of the primitive volume. Taking, therefore, the mean, we have

$$D = 0{\cdot}043859,$$

which is the *apparent* dilatation of water in glass from 0° to

80° R. To obtain the *true* dilatation between those limits, recourse must be had, as before, to the formula

$$\delta_{80} = 80\text{K} + (1 + 80\ \text{K})\ \text{D};$$

in which, substituting for K and D their values, we get ultimately

$$\delta_{80} = 0{\cdot}046601,$$

for the true dilatation of water between the temperatures of 0° and 80° R.

M. Biot has compared this result, also, with the experiments of Nollet, and traced the sources of disagreement. He then, as before, compares the results of his calculus with the experiments of Gilpin and Blagden, which he effects by means of the formula

$$\delta_{\text{T}} = \text{KT} + \frac{\text{D}}{80}(1 + \text{KT})\ \text{D}_{\text{T}};$$

thus obtaining the following table, in which the unit of volume is the primitive volume of water at 0°.

Degrees of the mercurial thermometer.	Corresponding degrees of therm. of water, computed.	True dilatation from the temperature of melting ice.		
		Computed.	Observed.	Excess of observation.
32° F. or 0° R.	0·0000	0·00000	0·00000	0·00000
40 3·56	− 0·3373	− 0·00007	− 0·00012	+ 0·00005
50 8·00	− 0.1220	+ 0·00019	+ 0·00014	− 0·00005
70 16·89	+ 2·3340	+ 0·00184	+ 0·00188	+ 0·00004
95 28·00	+ 8·9264	+ 0·00581	+ 0·00583	+ 0·00002
100 30·22	+ 10·6818	+ 0·00685	+ 0·00684	− 0·00001

The formula and the observations are evidently of equal accuracy. The deviations are all found in the order of hundred-thousandth parts of the unit. So that these experiments, which are so delicate to make, as their authors testify, are susceptible of confirmation from a calculus founded on the thermometrical observations of De Luc, combined with a single measure of the absolute dilatation of water. Hence, reducing the coefficients of δ_{T} into numbers, we obtain the following results for any temperature T expressed in degrees of Reaumur.

I. Degrees of the thermometer of water on its own scale,

$$= -\ 0{\cdot}16\text{T} + 0{\cdot}0185\text{T}^2 - 0{\cdot}00005\text{T}^3.$$

II. Apparent dilatation of the water in glass tubes,

$$\Delta_{\text{T}} = -0{\cdot}000087718\text{T} + 0.0000101424\text{T}^2 - 0{\cdot}00000002741 2\text{T}^3.$$

III. True dilatation,

$$\delta_{\text{T}} = -0{\cdot}000054878\text{T} + 0{\cdot}0000101395\text{T}^2 - 0{\cdot}000000027080\text{T}^3.$$

In this expression for the true dilatation the term that contains T^4, and of which the coefficient is 9 preceded by 12 ciphers between it and the decimal point, is suppressed. The

omission will only cause an error of 0·00004 of the primitive volume in the dilatation due to 80°. It must not be forgotten that the law of dilatation changes when other substances are dissolved in water.

The value of δ_T is susceptible of a *minimum* which shows us the *maximum* of condensation of pure water. The equation which determines this minimum is

$$0 = -0{\cdot}000054878 + 0{\cdot}000020279T - 0{\cdot}00000008124T^2.$$

Taking only the smaller root of this equation, it is $T = 2°{\cdot}736$ of Reaumur, or 3°·42 of the centesimal division. Mr. Gilpin and Sir Charles Blagden, according to Dr. Thomson, carry the true maximum of condensation to 3°·89 of the centesimal division; and Dr. Hope found it frequently at 3°·33. On this point there may be some minute differences, depending on the more or less perfect correspondence of the thermometers employed by the different observers, and probably on the greater or less degree of purity of the water employed; for we have seen that the mixture of foreign substances dissolved in water may not only depress the maximum of condensation, but even cause it to disappear entirely. But it is at least evident that this calculus so accords with the whole of the experiments, as to allow only very slight variations in reference to the point before us.

In a very curious series of experiments made by Sir Charles Blagden, to ascertain to what point water may, in certain circumstances, be cooled below zero without ceasing to be liquid, he has remarked that its retrograde dilatation continued even then, and that it became so rapid as to bear a considerable proportion to the total dilatation experienced by the water on passing into the state of ice*. This is an evident consequence of the formulæ. For, in the value of the apparent dilatation Δ_T, when T is positive, the terms tend to annihilate each other by the opposition of signs: while, below 0°, T becoming negative, all the terms take the same sign, and their *sum* is effective. To ascertain how far the difference may extend, let the value of Δ_T be computed from + 10° R. to — 10° R.; we shall then have

$$T = +10° \quad \text{- - - - - -} \quad \Delta_T = 0{\cdot}0001097$$
$$T = -10° \quad \text{- - - - - -} \quad \Delta_T = 0{\cdot}0019188;$$

* "In experiments where the water is cooled much below its freezing point, I have seen (says Sir Charles) the expansion so great as to bear a considerable proportion to the whole expansion produced by freezing, which last I believe is more than $\frac{1}{7}$ of the volume of the water. It seemed as if the expansion proceeded in an increasing ratio, being much greater on the last degree of cooling than it was on the first." Phil. Trans. vol. lxviii. New Abridgment, vol. xvi. 417.

where it is evident that the latter is to the former about in the ratio of 18 to 1.

14. Knowing the value of the true dilatation δ_T, it is easy thence to deduce the apparent dilatation in vessels of any substance whatever. For, denoting by K the cubic dilatation of the matter of which those vessels are constituted, the apparent dilatation Δ_T is given in general by the formula

$$\Delta_T = \frac{\delta_T - KT}{1 + KT}.$$

If we wish to ascertain the dilatation Δ_T simply for temperatures but little elevated, and those which always remain low, we may neglect the product of $\delta_T - KT$ by KT, and suppose the denominator of the second member equal to unity. In which case we shall have

$$\Delta_T = \delta_T - KT.$$

It is thus that we shall employ it in the use hereafter to be made of this formula. But for the greater simplicity, we shall substitute the letter a, c, b, for the numerical coefficients which δ_T contains, that is to say, we shall take generally

$$\delta_T = aT + bT^2 + cT^3.$$

a, b, and c, having values already determined. This substitution gives

$$\Delta_T = (a - K)\,T + bT^2 + cT^3.$$

15. The apparent dilatation Δ_T may be susceptible of a *minimum* depending on the dilatability of the matter of which the vessel is formed. The equation which determines this *minimum* is

$$\frac{\dot{\Delta}_T}{\dot{T}} = 0, \text{ or } 0 = a - K + 2bT + 3cT^2,$$

a quadratic equation, whose roots are

$$T = \frac{-b + \sqrt{[b^2 - 3(a-K)c]}}{3c}, \text{ and } T = \frac{-b - \sqrt{[b^2 - 3(a-K)c]}}{3c}.$$

These roots will be both positive so long as the substance of the vessel is of a nature to expand by heat: for, since a is negative as well as c, the product $3(a-K)c$ will then be positive: the value of the radical expression will therefore be less than that of b, and as the denominator $3c$ is negative, the two roots will have the sign $+$. But the first is the only one which interests us, because it is that which is always very small. To compute it exactly with facility, it will be advantageous to transform the equation by multiplying both terms of the fraction by $b + \sqrt{[b^2 - 3(a-K)c]}$, when it will become

$$T = \frac{a \quad K}{b + \sqrt{[l^2 - 3(a-K)c]}}.$$

It will then only be requisite to put for K its value in this formula, and we shall have the temperature T of the *apparent* maximum of condensation. The *absolute* maximum of condensation is found by making $K = 0$, when we have

$$T = -\frac{a}{b+\sqrt{(b^2-3ac)}}.$$

Since the value of c is extremely minute, if the temperature of the maximum should be very small also, we may, in approximations, neglect the term $3cT^2$ in the equation which determines that maximum; in which case we shall have

$$\textit{Apparent} \text{ maximum } T = -\frac{a}{2b} + \frac{K}{2b}.$$

$$\textit{True} \text{ maximum } (T) = -\frac{a}{2b}.$$

$$\text{Whence we deduce } T = (T) + \frac{K}{2b}.$$

This result shows how the apparent maximum depends upon the true maximum and the dilatation of the vessel. It shows that to obtain the temperature T of that maximum, it is requisite to have regard to the term which contains the square of the temperatures in the expression of the dilatation of water. But this more simple result is only an approximation; and the true expression, namely,

$$T = -\frac{a-K}{b+\sqrt{[b^2-3(a-K)c]}},$$

may differ from it very perceptibly, especially if the vessels are very dilatable; for then the values of K and T will both increase, and the error which may result from neglecting the term $3cT^2$ may be very considerable.

16. This result M. Biot applies to the experiments made by Mr. Dalton on the apparent maximum of condensation of water in expansible vessels*. To Dalton's results, Biot an-

* Nicholson's Journal, N. S. vol. x. p. 93. (1805.)

I shall throw into this note the principal part of Mr. Dalton's paper cited by M. Biot.

"A number of water thermometers are to be procured, the containing vessels of which are of different materials, as earthen ware, glass, and various metals. Each of these should contain one or two ounces (from 4 to 800 grains), more or less, of water. Common brown inkstands, which go by the name of Nottingham ware, answer very well for one species, but they require to be well painted without, as they are not otherwise water-tight. I have a few of Queen's ware, made purposely in Staffordshire, which constitute another species of earthen ware; some of them are glazed in and out; others unglazed, but these being painted without are water-tight, and expand the same by heat as glazed ones: Of glass, common thermometer tubes, with larger bulbs than ordinary, are sufficient. I have the metallic vessels made in the shape of cylindrical tin canisters, conical towards the top, and at the summit a small cylindrical tube,

nexes the cubic dilatations of the substances of which the vessels were formed.

such as to take a thermometer tube. The glazed earthen ware and the metallic require mostly to be painted before they are quite tight.

"The vessels being thus prepared, they are to be filled with water previously boiled to expel the air: a thermometer tube with cement is then suddenly plunged into the vessel and cemented fast; the water may then be driven out of the tube by heat, or more may be put into it by a small wire; it is then fit for use, and a scale of equal parts may be applied to the tube; or it may be divided, and marks made with a file or paint.

"Some of the results of my experiments with instruments of this kind are as follow: (Fahrenheit's Thermom.)

	Water lowest.	Water the same height.
1. Brown earthen ware, No. 1, at	36° -	at 32° and 40°
2. Brown earthen ware, No. 2,	38 -	- 32 and 44
3. Queen's ware, - -	40 -	- 32 and 48
4. Flint-glass, - -	41½ -	- 32 and 51
5. Iron, thin plate - -	42½ -	- 32 and 53
6. Tinned iron, - -	42½ -	- 32 and 53
7. Copper, - - -	45½ -	- 32 and 59
8. Brass, - - -	46 -	- 32 and 60
9. Pewter, - - -	46 -	- 32 and 60
10. Lead, - - -	49½ -	- 32 and 67

"Another phenomenon in these instruments is observable; it is not new, but it deserves a marked attention in the present inquiry: If the apparent expansion of water for the first 10° of temperature, reckoned from the lowest point in any of the above instrument, be denoted by 1; then if the instrument, taken at any temperature, be suddenly plunged in water of 10° higher temperature, the water instantly *sinks* a considerable way, occasioned no doubt by the vessel being extended by the heat before the water it contains has time to expand. The quantity of depression in the different instruments was found as under:

"Brown earthen ware sinks by being dipped in water of 10° higher temperature, - -	·2
Queen's ware, - - - - - -	·3
Flint-glass, - - - - - -	·25
Iron, - - - - - - -	·66
Copper, - - - - - - -	·9
Brass, - - - - - - -	1·1
Pewter, - - - - - - -	1·0
Lead, - - - - - - -	1·5."

Respective substances of the vessels.	Cubic dilatation for 1° R. according to Lavoisier and Laplace.	Maximum of condensation observed in degrees of Reaumur.	Degrees at which water stands at the same height.
Flint-glass -	0·00003003	4°·222	0° and 8°·444
Iron - - -	0 00004578	4· 667	9· 334
Copper - -	0·00006309	6· 000	12· 000
Brass - -	0·00007002	6· 222	12· 444
Pewter - -	0·00007266	6· 664*	13· 328
Lead - - -	0·00010689	7· 778	15· 555

The comparison of these results with the formulæ is exhibited in the following table.

Respective substances of the vessels.	Apparent maximum of condensation in degrees of Reaumur.		
	Computed.	Observed.	Excess of observation.
Flint-glass -	4°·236	4°·222	−0·014
Iron - - - -	5· 072	4· 667	−0·405
Copper - -	5· 960	6· 000	+0·040
Brass - - -	6· 319	6· 222	−0·097
Pewter - - -	6· 456	6· 664	+0·108
Lead - - - -	8· 246	7· 778	−0·468

The differences here evinced between the calculus and the experiments are by no means great. They may even arise from some slight differences between the expansions of the substances observed by Lavoisier and Laplace, and the expansions of those which constituted Mr. Dalton's vessels; and so much the rather, as the errors of expansion become extremely augmented by the smallness of the divisor by which they are affected in the expression for T. But farther, as the deviations are marked generally by the negative sign, M. Biot is inclined to think, that the water employed by Mr. Dalton, at least in

* This value, 6·664, is employed as it appears, tom. ii. p. 156. of the French translation of Thomson's Chemistry. In Nicholson's Journal, the number for pewter is the same as for brass; which M. Biot regards as an erratum, especially as the value given by Dr. Thomson agrees very well with the theory.

some of his experiments, was not perfectly pure, but that it contained a small quantity of some saline substance, which rather depressed its maximum of condensation. This may explain why, on employing vessels whose dilatation was almost imperceptible, as earthen-ware, for example, Mr. Dalton has found the apparent maximum lower than the ordinary term of the true maximum, and once among others at $+1^{\circ}{\cdot}78$ Reaumur; while Biot's formula for pure distilled water gives the true maximum at $2^{\circ}74$ R., almost 1° R. higher than Dalton's servation.

Mr. Dalton has also observed that in his vessels the water is made to stand at equal altitudes by equal changes of temperature above or below that which answers to the apparent maximum of condensation. This, again, is a consequence of our formula. The general expression of the apparent dilatation Δ_T in these lower temperatures is

$$\Delta_T = (a - K)T + b^2 + cT^3;$$

and putting T' for the temperature at the apparent maximum of condensation, we have seen that this temperature is given by the equation

$$0 = a - K + 2bT' + 3cT'^2.$$

Making, in general, $T = T' + t$, that is, reckoning the temperatures above and below the maximum of apparent condensation, and substituting this value of T in Δ_T there will arise

$$\begin{aligned} \Delta_T = (a-K)T' &+ bT'^2 + cT'^3 \\ + (a-K)t &+ 2bT't + 3cT'^2t \\ &+ bt^2 + 3cT't^2 \\ &+ ct^3 \end{aligned}$$

The first line is constant: it is the value of the dilatation Δ_T at the epoch of the maximum of condensation; we shall represent it by $\Delta_{T'}$. The second line has every line multiplied by the first power of t; so that the factor of t is $a - K + 2bT' + 3cT'^2$; and this factor vanishes entirely, since T' is determined precisely by the condition of rendering it nothing. Thus, when the requisite reductions are made, the expression for Δ_T will become,

$$\Delta_T = \Delta_T + (b + 3cT')t^2 + ct^3.$$

We have seen that the co-efficient c is very small; for we have $c = -0{\cdot}00000002708$. Consequently, if the comparison

of the temperatures be extended to $\pm 20°$R. there will result

$$ct^3 = \mp 0{\cdot}0002166;$$

so that this term cannot produce an irregularity of more than about $\frac{1}{5000}$ part of the total volume of water at 0°; and if we take $t = \pm 10°$R. it will be *eight* times less, or $\frac{1}{40000}$ part of the primitive volume. Thus, it is evident, that unless the experiments have a mathematical precision, the effect of the term that contains t^3 cannot be perceived. Neglecting it, therefore, the value of Δ_{T} is reduced to

$$\Delta_{\text{T}} = \Delta_{\text{T}}' + (b + 3c\text{T}')t^2;$$

and this manifestly remains the same at equal values of t whether positive or negative; which is the very property observed by Mr. Dalton.

The same able philosopher has also observed the quantity by which the water is suddenly depressed in vessels of different substances, when they are immersed in heated liquid. He found that this quantity was different, according to the nature of the vessel, and so much the greater, as it is made of a more expansible substance. Whence he naturally concluded that this sudden depression is occasioned by the dilatation of the metal, which, propagating heat more rapidly than water, becomes heated before it and dilates first. What manifests this still better, is that the quantities of the depression given by Mr. Dalton are very nearly proportional to the cubic dilatations of the substances of which the vessels were made. The vessel of pewter seemed alone to present an exception. But, if the deviation is not to be ascribed to an error of the press, it may arise from the extreme difficulty that attends the making of such delicate experiments, and of measuring the sudden depression of the water, before it had acquired any sensible augmentation of heat.

17. These researches into the dilatation of liquids are terminated by pointing out a process which results from them, (and which appears both simple and exact) for measuring the differences in the dilatations of solid bodies. It consists in observing the apparent dilatation of a liquid, mercury for example, in vessels made of the substances whose expansions we wish to ascertain, and in observing it always between constant temperatures, between 0° and 80°R. for instance. This apparent dilatation may be observed very early, with all desirable precision. When it becomes known for vessels formed of a substance whose cubic dilatation is K, we

shall have betwen the true and apparent dilatation, Δ_T and δ_T, the equation

$$\Delta_T(1+KT5=\delta_T-KT:$$

$$\text{this gives } (1+\Delta_T)TK=\delta_T-\Delta_T.$$

For another kind of vessel subjected to the same temperatures, we shall have, in like manner,

$$(1+\Delta'_T)TK'=\delta_T-\Delta'_T,$$

δ_T remaining the same because the same liquid is employed all along. Taking one of these equations from the other δ_T will be made to disappear, and there will remain

$$(1+\Delta'_T)TK'-(1+\Delta_T)TK=\Delta_T-\Delta'_T;$$

whence we have

$$K'=K+\frac{(\Delta_T-\Delta'_T)(1+KT)}{T(1+\Delta'_T)}.$$

In the actual state of physics, the dilatations of the metals are known with sufficient exactness to enable us to employ them in computing the small correction dependent on K in the second member in the preceding equation; then, by putting for Δ_T, Δ'_T, and T, their values observed; $K'-K$ will become known. The accuracy of these values will be so much the greater, as Δ_T, and Δ'_T are inferred from larger volumes; and thus, also, it will be with respect to the difference $K'-K$ of the cubic dilatations determined by that equation. Perhaps, in operating on the most dilatable metals, it will be necessary to retain the term proportional to K^2T^2, which was neglected at the commencement of this paper. It is by farther experiment we must ascertain whether it will become perceptible.

To obtain the absolute values of K and K' by the same procedure, the true dilatation δ_T, must be known for the liquid employed in the experiments. This may be ascertained by observing that dilatation in a non-dilatable vessel; and it is easy to construct one which shall possess that property, that is to say, which shall include the principle of self-compensation, when the difference of dilatation in the metals is known.

M. Biot thinks this process will furnish a simple and exact method of comparing the progress of the dilatation of mercury with that of metals; which is now the only thing remaining to be done in order to refer all the dilatations to the air thermo-

meter, the most perfect of all: for, as to the absolute dilatations of metals, they now appear perfectly known by means of the experiments of Lavoisier and Laplace.

Adopting them we possess the means of computing the true dilatations of liquids, when we know their apparent dilatations in vessels of known nature. To determine the law of these latter, relatively to a given liquid, we must commence by constructing a thermometer freed from air, and compare it carefully with the mercurial thermometer. The co-efficients A, B, C, must be determined from three of those observations, and we must see whether all the others are comprehended in the same law. It will only remain to determine a single value of the absolute dilatation between two known temperatures, which will be easily effected by means of the weights; and with these data the computation will make known the true or apparent volume of the liquid at any temperature whatever.

Addition to the preceding paper.—The relations established in the foregoing paper, between the dilatations of several liquids and the degrees of the mercurial thermometer, are independent of all hypothesis. It is sufficient that we can determine by computation the volume of each of such liquids at a temperature given by the thermometer; or, reciprocally, that we can compute the temperature, the volume being given.

The apparent dilatation of mercury in glass is taken, here, for a standard to which all the others are referred. We might similarly have referred the variable volume to all other dilatations; its absolute values would then remain the same, but the form of the function which expresses it would change. This is precisely what has been done by Mr. Dalton in his "Chemical Philosophy." That able philosopher having remarked that the dilatations of water increased very nearly as the squares of the temperatures reckoning from the maximum of condensation, has concluded that it ought to be the same for all liquids whose composition remains constant during their change of volume; and that if the same law of the squares was not strictly observed for water, it was because the progress of the mercurial thermometer was not exactly proportional to the heat. He has conceived the notion of substituting for this latter thermometer an ideal thermometer, which shall be possessed of this property, such as we might imagine to be the case, for example, in a thermometer of air. He has supposed that the dilatations of the mercury, expressed in functions of the ideal thermometer, ought equally to observe the law of the squares, reckoning from the point of congelation; and he has thought that, on calculating in like manner the dilatations of

all the other liquids on this ideal thermometer, they will all be found to conform to the same law.

This hypothesis gives immediately the form of the function which should express the correspondence between the *mercurial* and the *ideal* thermometer. Conceive both thermometers adjusted to the extreme points of melting ice and boiling water; conceive, moreover, that in both of them the interval between these points is divided into 80 parts, as in the thermometer of De Luc. Then, if both instruments be immersed in the same liquid, the first indicating T degrees, the second t; the relation of T to t, according to the hypothesis, will be necessarily of this form,

$$\text{T} = a' t + b' t^2.$$

Since it is necessary that there be a *maximum*, reckoning from which it shall vary as the squares of the temperatures; let (t) be the true temperature of that maximum, we shall then have

$$\frac{\dot{\text{T}}}{\dot{t}} + 0, \text{ or } a' + 2b'(t) = 0.$$

But, since this ought to answer to the point of congelation of mercury, for which we have $\text{T} = -32^\circ$ R. we shall have

$$-32 = a'(t) + b'(t)^2.$$

The first of these equations gives $(t) = -\frac{a'}{2b'}$: substituting this value in the second, it becomes

$$32 = \frac{a'^2}{4b'}, \text{ or } b' = \frac{a'^2}{128}.$$

Now, it is necessary that the two thermometers, which before coincided at 0°, coincided also at 80°. In order to this we must have simultaneously $\text{T} = +80^\circ$, and $t = +80^\circ$, which gives the condition

$$a' + 80\, b' = 1:$$

this, joined to the preceding, determines a' and b'; thus they are found to be, very nearly,

$$a' = \frac{184}{264},\ b' = \frac{1}{264}.$$

There is another value of a', but it is not admissible, because it would cause T to diminish while t augments. Substituting, then, the above values in the general equation for T, it becomes

$$\text{T} = \frac{184}{264}\, t + \frac{1}{264}\, t^2.$$

This formula exhibits the correspondence of the mercurial thermometer with the ideal thermometer, as it results from Mr. Dalton's hypothesis. In fact, the results which we have de-

deduced from it are conformable to those which this able philosopher has given in his new tables of temperature, pa. 14. The first column of the table contains the number of degrees indicated by the ideal thermometer: Mr. Dalton calls them *true temperatures*. The values of T which correspond to them form the third column of the table; the degrees being all along expressed in the division of Fahrenheit, instead of that of Reaumur, which we have adopted in this paper. The next column presents the same degrees T affected by the expansion of glass. The point on the thermometric scale between 0° and 80°, where T differs most from t, answers to $t = 40°$, which gives T $= 34°$; the difference is 6° by which t exceeds T at that period. Mr. Dalton finds 5°·3 for this difference; probably because of the minute fractions which we have neglected when resolving the equation for a' by approximation; and perhaps, also, because Mr. Dalton has conducted his computations differently, though on the same principles.

This hypothesis being now reduced to its simplest terms, a reflection naturally presents itself; which is, that considered only in itself, it is extremely improbable, since it assigns necessarily to mercury and to all liquids a maximum of true condensation, fixed at their point of congelation. In truth, the mere mathematical enunciation of this hypothesis leads at once, for mercury, to an expression of the form

$$\mathrm{T} = a' t + b' t^2;$$

where T has necessarily a minimum when

$$t = -\frac{a'}{2b'}.$$

For, if we make $t = -\frac{a'}{2b'} + t'$, which amounts to the same as reckoning the temperatures t' from the point when $t = -\frac{a'}{2b'}$, we shall find

$$\mathrm{T} = -\frac{a'^2}{4b'} + b' t'^2;$$

whence it is evident that the values of T are the smallest possible when t' is nothing, and go on augmenting from that term, at least if b' be positive. With regard to mercury, for example, we shall have

$$\frac{a'^2}{4b'} = 32;$$

and consequently $\mathrm{T} = -32 + t'^2 \cdot \frac{t'^2}{264}$,

Thus, according to Mr. Dalton's hypothesis, the common mercurial thermometer can never descend lower than 32°R. below zero, which is the point of congelation of that liquid.

But this is altogether contrary to experience; for it is known that all the liquids hitherto observed may, with certain precautions, be cooled below their point of congelation without becoming solid, and then, so long as they remain liquid, they will continue to conform to their respective law of dilatation. It is thus that *water*, for example, dilates by quantities equal as to sense, reckoning either way from its maximum of density, to at least 10°R. ascending or descending. In like manner, *olive oil*, which congeals in open air, at a temperature by no means low, may be cooled far below that point, nay even to 14°R. below 0, without ceasing to be liquid, as is proved by the experiments of De Luc; and in that state it continues to contract, according to the law which it followed in the rest of the thermometric scale; since, as we have shown (§ 1.) that law does not permit a maximum of condensation. It is the same with respect to *mercury*, as is proved by the disquisition of Mr. Cavendish on Hutchins's experiments at Hudson's Bay. For it results from that disquisition that mercury, as well as other liquids, may be cooled below its point of fusion without becoming solid, that this frequently happened in the experiments of Mr. Hutchins, and that when it has happened, the mercury, so long as it remained fluid, continued to contract progressively to the moment of its solidification, when it contracted all at once in a proportion much more considerable *. All these results are contrary to the idea of such a law of dilatation as is supposed by Mr. Dalton; and the same contradiction will subsist in reference to all liquors which contract progressively down to the instant of their solidification.

If, notwithstanding these physical contradictions, we would verify the hypothesis of Mr. Dalton even by the experiments made in reference to the dilatation of water, which is the principal object he had in view, we shall find that it agrees with it much less exactly than the empyrical law deduced from the thermometrical observations; which is very natural, since these observations have offered to us an extremely delicate proof on which our formulæ are moulded. All along we conceive that a slight change of the thermometric scale, such as that which results from Dalton's hypothesis between 0 and 80°, cannot produce a very considerable effect on a liquid which dilates so little as water; and so much the more as Mr. Dalton has compensated in part the excess of his scale of true temperatures by the excess of true temperature which he ascribes to the maximum of condensation. But the error may become greater in proportion as we apply that scale to other liquids of which the expan-

* Phil. Trans. vol. lxxiii. p. 303, New Abridgment, vol. xv. p. 420.

sion is comparatively greater, alcohol, for example, and this, in fact, has occurred. Mr. Dalton himself has acknowledged that the law of dilatation deduced from his hypothesis does not accord with the thermometrical observations of De Luc, especially at high temperatures. Struck with this discordance, he has been led to throw some doubts on those observations themselves: "for, (says he) as the dilatation of alcohol from 62° to 80° R. must have been conjectural, it may be that De Luc has exaggerated it." But the observations of De Luc, and of many other philosophers, have long ago shown, that when a liquid is included in a vacuum, it may support without boiling temperatures much superior to those at which it boils under the pressure of common atmospheric air; and Mr. Dalton's theory of the formation of vapours, assigns an obvious reason for this fact. There have also been long made thermometers of alcohol, purged of air, which sustain perfectly the temperature of boiling water. It appears from our formulæ that the dilatation of alcohol between these extreme limits, so far from being irregular and capricious, continues to be conformable to itself, and conforms to the same law at the temperature of boiling water, and at 10° R. below zero. Only, as this dilatation is not proportional to that of mercury, it is manifest that its absolute value is not the same in the different parts of the thermometric scale, for the same number of degrees. This is found confirmed in the most striking manner, by means of an observation of the absolute dilatation of alcohol, made by Mr. Dalton himself in a glass vessel, between −17°.78 R. and + 62°.22 R. comprehending an interval of 80°. The dilatation in this interval ought not to be the same as from 0 to 80°. Calculating by our formula, we find

From 0 to − 17·78, true dilatation .	−0·0209325
From 0 to +62·22, true dilatation .	+0·0919566
Difference, or total dilatation betweeen − 17·78 and + 62·22 . . . δ_T	+0·1128891
From which deducting the dilatation of glass . − 80 K	0·0026272
We have the apparent dilatation between the same limits	0·1102619
The value found experimentally by Mr. Dalton is	0·110

This agrees precisely with the computation so far as the decimals, in the experimented number, serve for the comparison. This confirmation of the formula is so much the more satis-

factory, as their determination was independent of all observations below zero.

Mr. Dalton's work likewise contains a confirmation of the value attributed by Biot to the absolute dilatation of water between the temperatures of 0 and 80° R. For, from experiment, he assigns it at 0·0466, precisely the same as has been inferred by Biot from the thermometrical observations of De Luc, combined with a single determination of the specific gravity of water at the temperature of 30°.22 by Gilpin and Blagden.

M. Laplace, whose views in relation to physical subjects are always as ingenious as extensive and profound, undertook to investigate whether it were or were not possible to make the term depending on the cubes of the temperatures disappear, by referring all the dilatations to an ideal thermometer, in functions of which even that of mercury should be expressed in the same manner by a simple law of the squares, reckoning for each liquid from a different point. But he has assured M. Biot that the requisite accuracy cannot be generally acquired in this way, at least with the coefficients *he* has deduced. For their signs as well as their values changed for the different liquids, in such manner that it is impossible to make the term which depends on the cube of the temperature disappear in all these liquids, by a single supposition for the dilatation of mercury in functions of the ideal thermometer. Perhaps, more exact experiments than those made use of by M. Biot may some time lead to the discovery of a more simple law; but, till then, the formulæ exhibited in this paper will suffice for the ordinary purposes of observers. See, also, on these subjects, *Bland's Hydrostatics*, § viii.

THRASHING MACHINES, in a country like ours, where agriculture has been so successfully cultivated, can hardly be denied to be of great utility: for which reason, although these machines are not yet brought to such a state of perfection as is to be wished, we conceive it will not be improper to give an account of some of the most ingenious.

The first thrashing-machine which has come to our knowledge is that manufactured in 1732, by Mr. *Michael Menzies* of Edinburgh; it consisted, as far as we have been able to ascertain, of numerous instruments resembling flails, which were attached to a moveable beam, and inclined to the latter in an angle of ten degrees. On each side of such beam were placed floors, or benches, on which the sheaves were spread; the flails being moved forward and backward on these benches by a crank that was fixed to the end of an axle, revolving about thirty times in a minute.

The second machine was invented in 1753 by Mr. *Michael*

Sterling of Dumblane, Perthshire: his first models were very imperfect; but, after repeated alterations, he completed it in its present form, in 1758; and it now consists of an outer, or water-wheel, having an inner wheel, furnished with forty-eight cogs, and turning on the same axle. With this cog-wheel is connected a vertical trundle, or pinion, with seven notches; and the axle of which passes through a floor above the wheel; its upper pivot being secured in a beam six inches above the floor. At the height of three feet three inches from the latter, two straight pieces of squared wood (each being four feet in length) are inserted through the axle of the pinion, at right angles, so as to form four arms that are moved round horizontally. To the end of these arms are affixed four iron plates, each twenty inches in length, and eight inches in breadth at the extremity nearest to the arms, but tapering to a point at the opposite ends.

The horizontal fly, here described, constitutes four thrashers, and is inclosed in a cylindrical wooden box, that is three and a half feet high, and eight feet in diameter: on the top of this box is an opening eight inches in width, extending a foot and a half from the circumference to its centre, and through which the sheaves of corn descend; the latter being previously opened, and laid separately on a board provided with two ledges gradually declining towards such port, or opening. Within the cylindrical box there is an inclined plane, along which the straw and grain fall into a wire-riddle two feet square, that is placed immediately beneath a hole of a similar size: the riddle is jerked at each revolution of the spindle, by means of a knob fixed on its side; and is thrust backward by a small spring that presses it in a contrary direction. Thus, the short straw, together with the grain and chaff, that pass through the wide riddle, fall instantly into an oblong straight riddle, one end of which is raised, and the other depressed, by a similar contrivance. And, as the riddle last mentioned is not provided with a ledge at the lower end, the long chaff, which cannot pass through, drops thence to the ground, while the grain and smaller chaff descend into a pair of common barn-fanners, and are thus separated with great exactness. These fanners are moved by means of a rope, that runs in a shallow groove cut on the circumference of the cog-wheel. In the meantime, the straw collected in the lower part of the box over the wide riddle, and through an opening two feet and a half square, is drawn down to the ground with a rake, by the persons employed to form it into trusses.

In 1772, another thrashing-machine was invented by Mr. *Alderton* of Alnwick, and Mr. *Smart* of Wark, Northumber-

land. The operation was performed by rubbing: the sheaves being carried round between an indented drum six feet in diameter, and numerous indented rollers, that were arranged round, and attached to, this drum by means of springs; so that during the revolution of the machinery, the corn was separated from the straw by constant friction against the flutings of the drum. But this contrivance was soon disused; as many grains were thus crushed between the rollers.

The next invention is that of Mr. *Andrew Meikle*, in 1785, who obtained a patent, which is now expired; we have therefore given a plate (XXXIV), representing in fig. 1. the plan of elevation; in fig. 2. the ground plan; and in fig. 3. the essential parts of the machinery, so as to convey a tolerably accurate idea of his principle.

A (fig. 1. and 2.) is a large horizontal spur-wheel, which has 276 cogs, and moves the pinion B, having fourteen teeth. The latter imparts motion to a crown-wheel, C, that is provided with eighty-four cogs, and moves a second pinion, D, which is furnished with sixteen teeth. This pinion D turns the drum HIKL (fig. 1. 2. and 3.), being a hollow cylinder, three feet and a half in diameter, and placed horizontally: on its outside are fixed, by means of screw-bolts, four scutchers, or pieces of wood, one side of which is faced with a thin iron plate; and which are disposed at an equal distance from each other, and at right angles to the axis of the drum.

F (fig. 2. and 3.) is an inclined board, on which the sheaves are spread, and whence they are introduced between two fluted cast-iron rollers, G, G (fig. 3.), that are three and a half inches in diameter, and revolve about thirty-five times in one minute. These rollers being only three-fourths of an inch from the scutchers or leaves of the drum HIKL (fig. 1. and 2.), serve to keep the sheaves steady, while the scutchers *a*, *b*, *c*, *d*, (fig. 2. and 3.) move with considerable velocity, and thus separate the grain from the straw, while both are thrown on the concave rack M (fig. 2.), which lies horizontally with slender parallel ribs; so that the corn may pass through them into the subjacent hopper N (fig. 1. and 3.).

O (fig. 3.) is a riddle or harp, through which the corn drops into a pair of fanners, P (fig. 1. and 3.), and from these it is generally obtained in a state fit for the market.

QRTS is a rake, consisting of four leaves, or thin pieces of wood; at the extremity of each is placed a row of teeth, *e*, *f*, *g*, *h*, that are five inches long. This rake moves in the concave rack M, (fig. 2.), in a circular direction; while the teeth catch the straw that had been thrown by the scutchers *a*, *b*, *c*, *d*, into the rack, and remove it to the contiguous place, V.

W (fig. 1.) represents the horse's course, which is twenty-seven feet in diameter.

X (fig. 1. and 2.) is the pillar for supporting the beams on which the axle of the spur-wheel is fixed.

Y, Y, Y (fig. 1.), and Y, Y (fig. 2.), show the spindles, the design of which is to move the two fluted rollers, the rake, and the fanners.

To the description now given we have only to add, that the drum has a covering of wood at a small distance above it, for the purpose of keeping the sheaves close to the scutchers.

The number of persons requisite for attending the mill when working is six: one person drives the horses; a second hands the sheaves to a third who unties them, while a fourth spreads them on the inclined boards, and presses them gently between the rollers: a fifth person is necessary to riddle the corn as it falls from the fanners, and a sixth to remove the straw.

This machine can be moved equally well by water, wind, or horses. Mr. Meikle has made such improvements on the wind-mill as to render it much more manageable and convenient than formerly; and we are informed many wind-mills are now erecting in different parts of the country. As to the comparative expense of these different machines, the erection of the horse-machine is least; but then the expense of employing horses must be taken into consideration. One of this kind may be erected for 70*l.* A water-mill will cost 10*l.* more, on account of the expense of the water-wheel. A wind-mill will cost from 200*l.* to 300*l.* sterling.

In thrashing-machines, however, cheapness should not be the only consideration. It often happens in machinery, that things apparently cheap are ultimately very dear. Thrashing of corn requires a strong power, which neither weak men nor slight machines are competent to. On this account, strong and durable machines are to be recommended as cheapest in the end; performing more work, in a better manner, and not needing frequent repairs.

Some other well-constructed thrashing-machines are described in Gray's Experienced Millwright, Bailey's Descriptions of Machines approved by the Society of Arts, in the Repertory of Arts and Manufactures, the 2d vol. of Dr. Brewster's Ferguson, and the 11th vol. of the Pantologia.

With respect to the quantity of corn which a machine will thrash in a given time, it is not easy to give any precise information; the most important we have yet met with is given by Mr. Fenwick, who found from numerous experiments that a power capable of raising a weight of 1000 pounds with a uniform velocity of fifteen feet per minute, will thrash two bolls

(eight bushels) of wheat in an hour; and that a power sufficient to raise the same weight with a velocity of twenty-two feet per minute will thrash three bolls of the same grain in an hour. From these facts, this gentleman has computed the following table, which is applicable to machines that are driven either by water or horses.

TABLE *of the power of thrashing-machines.*

Gallons of water per minute, ale-measure, discharged on an over-shot wheel 10 feet in diameter.	Gallons of water per minute, ale-measure, discharged on an over-shot wheel 15 feet in diameter.	Gallons of water per minute, ale-measure, discharged on an over shot wheel 20 feet in diameter.	Number of horses working $9\frac{1}{2}$ hours.	Bolls of wheat thrashed in an hour.	Bolls thrashed in $9\frac{1}{2}$ hours actual working, or, in a day.
230	160	130	1	2	19
390	296	205	2	3	$28\frac{1}{2}$
528	380	272	3	5	$47\frac{1}{2}$
660	470	340	4	7	$66\frac{1}{2}$
790	565	400	5	9	$85\frac{1}{2}$
970	680	500	6	10	95
1	2	3	4	5	6

The first four columns of the preceding table contain different quantities of impelling power, and the last two exhibit the number of bolls of wheat in Winchester measure which such powers are capable of thrashing in an hour, or in a day. Six horses, for example, are capable of thrashing ten bolls of wheat in an hour, or ninety-five in the space of nine hours and a half, or a working day; and 680 gallons of water discharged into the buckets of an overshot water-wheel of 15 feet diameter during a minute will thrash the same quantity of grain.

TIDE-MILLS, as their name imports, are such as employ for their first mover the flowing and ebbing tide, either in the sea or a river.

Mills of this kind have not often, we believe, been erected in England, though several of our rivers, and particularly the Thames, the Humber, and the Severn, in which the tide rises to a great height, furnish a very powerful mover to drive any kind of machinery, and would allow of tide-mills being very advantageously constructed upon their banks. The erection of

such mills is not to be recommended universally, as they are attended with a considerable original expense; besides that some of their parts will require frequent repairs: but in some places where coals are very dear they may, on the whole, be found less expensive than steam-engines to perform the same work, and may on *that* account be preferred even to them.

We have not been able to ascertain who was the first contriver of a tide-mill in this country, nor at what time one was first erected. The French have not been so negligent respecting the origin of this important invention as to let it drop into obscurity; but have taken care to inform us that such mills were used in France early in the last century. Belidor mentions the name of the inventor, at the same time that he states some peculiar advantages of this species of machine. "L'on en attribue," says he, "la première invention à un nommé *Perse*, maître charpentier de Dunkerque, qui mérite assurément beaucoup d'éloge, n'y ayant point de gloire plus digne d'un bon citoyen, que celle de produire, quelqu' invention utile à la société. En effet, combien n'y-a-t-il point de choses essentielles à la vie, dont on ne connoît le prix que quand on en est privé? Les moulins en général sont dans ce cas-là. On doit scavoir bon gré à ceux qui nous ont mis en état d'en construire par-tout: par exemple à Calais, comme il n'y serpente point de rivieres, on n'y a point fait jusqu'ici de moulins à eau, & ceux qui vont par le vent chômant un partie de l'année, il y a des tems où cette ville se trouve sans farine; & j'ai vu la garnison en 1730, obligée de faire venir du pain de Saint-Omer, au lieu qu'en se servant du flux & reflux de la mer, on pourroit construire autant de moulins à eau que l'on voudroit: il y a d'autres villes dans le voisinage de la mer sujettes au même inconvénient, parce qu' apparement elles ignorent le moyen d'y remédier."

Mills to be worked by the rising and falling of the tide admit of great variety in the essential parts of their construction; but this variety may perhaps be reduced to four general heads, according to the manner of action of the water-wheel. 1. The water-wheel may turn one way when the tide rises, and the contrary when it falls. 2. The water-wheel may be made to turn always in one direction. 3. The water-wheel may fall and rise as the tide ebbs and flows. 4. The axle of the water-wheel may be so fixed as that it shall neither rise nor fall, though the rotatory motion shall be given to the wheel, while at one time it is only partly, at another completely, immersed in the fluid. In the mills we have examined, the first and third of these divisions have been usually exemplified in one machine; and the second and fourth may readily be united in another: we shall, therefore, speak of them under two divisions only.

1. *When the water-wheel rises and falls, and turns one way with the rising tide, and the contrary when it ebbs.* In order to explain the nature of this species of tide-mill, we shall describe one which has been erected on the right bank of the Thames at East Greenwich, under the direction of Mr. John Lloyd, an ingenious engineer, of Brewer's-green, Westminster.

This mill is intended to grind *corn*, and works 8 pairs of stones. The side of the mill-house parallel to the course of the river measures 40 feet within; and as the whole of this may be opened to the river by sluice-gates, which are carried down to the low water-mark in the river, there is a forty-feet water-way to the mill: through this water-way the water passes during the rising tide into a large reservoir, which occupies about 4 acres of land: and beyond this reservoir is a smaller one, in which water is kept for the purpose of being let out occasionally at low water to cleanse the whole works from mud and sediment, which would otherwise in time clog the machinery. The water-wheel has its axle in a position parallel to the side of the river, that is, parallel to the sluice-gates which admit water from the river: the length of this wheel is 26 feet, its diameter 11 feet, and its number of float-boards 32. These boards do not each run on in one plane from one end of the wheel to the other, but the whole length of the wheel is divided into four equal portions, and the parts of the float-boards belonging to each of these portions fall gradually one lower than another, each by one-fourth of the distance from one board to another, measuring on the circumference of the wheel. This contrivance, which will be better understood by referring to fig. 6. pl. XXXV. (showing a part of the wheel), is intended to equalize the action of the water upon the wheel, and prevent its moving by jerks. The wheel, with its incumbent apparatus, weighs about 20 tons, the whole of which is raised by the impulse of the flowing tide when admitted through the sluice-gates. It is placed in the middle of the water-way, leaving a passage on each side of about 6 feet for the water to flow into the reservoir, besides that which in its motion turns the wheel round. Soon after the tide has risen to the highest (which at this mill is often 20 feet above the low water-mark), the water is permitted to run back again from the reservoir into the river, and by this means it gives a rotatory motion to the water-wheel, in a contrary direction to that with which it moved when impelled by the rising tide: the contrivance by which the wheel is raised and depressed, and that by which the whole interior motions of the mill are preserved in the same direction, although that in which the water-wheel moves is changed, are so truly ingenious as to deserve a distinct description, illustrated by dia-

grams. Let, then, AB (fig. 5. pl. XXXV.) be a section of the water-wheel, 1, 2, 3, 4, 5, &c. its floats, CD the first cog-wheel upon the same axis as the water-wheel: the vertical shaft PE carries the two equal wallower-wheels E and F, which are so situated on the shaft that one or other of them may, as occasion requires, be brought to be driven by the first wheel CD; and thus (by what has been said under the article REVERSING *of motions*) the first wheel acting upon F and E at points diametrically opposite, will, although its own motion is reversed, communicate the rotatory motion to the vertical shaft always in the same direction. In the figure the wheel E is shown in gear, while F is clear of the cog-wheel CD; and at the turn of the tide the wheel *f* is let into gear, and E is thrown out: this is effected by the lever G, whose fulcrum is at H, the other end being suspended by the rack K, which has hold of the pinion L on the same axle as the wheel M; into this wheel plays the pinion N, the winch O on the other end of whose axle furnishes sufficient advantage to enable a man to elevate or depress the wallower-wheels, as required. The centre of the lever may be shown more clearly by fig. 6. pl. XXXV. where *ab* is a section of the lever, which is composed of two strong bars of iron, as *ab*: there are two steel studs or pins which work in the grooves of the grooved wheel I, this wheel being fixed on the four rods surrounding the shaft, of which three only can be shown in the figures, as *c*, *d*, *e*; the ends of these are screwed fast by bolts to the sockets of the wallower-wheels, and they are nicely fitted on the vertical shaft, so as to slide with little friction: thus the wallowers may be raised or lowered upon the upright shaft, while the gudgeon on which it turns retains the same position. When the top wallower is in gear, it rests on a shoulder that prevents it from going too far down; and when the bottom one is in gear there is a bolt that goes through the top wheel socket and shaft, which takes the weight from the lever G, at the same time that it prevents much friction on the studs or pins of the lever which works in the grooved wheel I.

When the tide is flowing, after the mill has stopped a sufficient time to gain a moderate head of water, the fluid is suffered to enter and fall upon the wheel at the sluice Q (fig. 5.), and the tail-water to run out at the sluice R. The hydrostatic pressure of the head of water acting against the bottom of the wheel-frame S, and at the same time acting between the folding-gates TW, which are thus converted into a very large hydrostatic bellows, buoys up the wheel and frame (though weighing, as before observed, nearly 20 tons), and makes them gradually to rise higher and higher, so that the wheel is never, as

the workmen express it, *drowned* in the flowing water; nor can the water escape under the wheel-frame, being prevented by the folding-gates, which pass from one end to the other of the wheel. In this way the wheel and frame are buoyed up by a head of 4 feet; and the mill works with a head of 5 or $5\frac{1}{2}$ feet.

When the tide is ebbing, and the water from the reservoir running back again into the river, it might perhaps be expected that in consequence of the gradual subsiding of the water the water-wheel should as gradually lower: but lest any of the water confined between the wheel-frame at S and the folding-gates TW should prevent this, there are strong rackworks of cast-iron, by which the wheel-frame can be either suspended at any altitude or gradually let down so as to give the water returning from the reservoir an advantageous head upon the wheel: then the sluice R is shut, and V opened as well as X, the water entering at X to act upon the wheel, and flowing out at R. The upper surface of the wheel-frame is quadrangular, and at each angle is a strong cast-iron bar, which slides up and down in a proper groove, that admits of the vertical motion, but prevents all such lateral deviation as might be occasioned by the impulsion of the stream.

At each end of the water-wheel there is a vertical shaft, with wallowers and a first cog-wheel, as F, E, and CD; and each of these vertical shafts turns a large horizontal wheel at a suitable distance above the wallowers, while each horizontal wheel drives 4 equal pinions placed at equal or quadrantal distances on its periphery, each pinion having a vertical spindle, on the upper part of which the upper millstone of its respective pair is fixed. Other wheels driven by one or other of these pinions giving motion to the bolting and dressing machines, and different subordinate parts of the mill.

Although the vertical shaft at each end of the water-wheel rises and falls with that wheel, yet the large horizontal wheel turning with such shaft does not likewise rise and fall, but remains always in the same horizontal plane, and in contact with the four pinions it drives. The contrivance for this purpose is very simple, but very efficacious: each great horizontal wheel has a nave, which runs upon friction-rollers, and has a square aperture passing through it vertically, just large enough to allow the shaft P to slide freely up and down in it, but not to turn round without communicating its rotatory motion to the wheel: thus the weight of the wheel causes it to press upon the friction-rollers, and retain the same horizontal planes, and the action of the angles of the vertical shaft upon the corresponding parts of the square orifice in the nave causes it to

partake of the rotatory motion, such motion being always in one direction, in consequence of the contrivance by which one or other of the wallowers EF is brought into contact with the opposite points of the first cog-wheel CD.

Several of the subordinate parts of this mill are admirably constructed; but we can only notice here the means by which the direction of the motion in the dressing and bolting machines may be varied at pleasure. On a vertical shaft are fixed, at the distance of about 15 or 18 inches, two equal cog-wheels, and another toothed wheel attached to a horizontal axle is made so as to be moveable up and down by a screw, and thus brought into contact with either the upper or lower of the two cog-wheels on the vertical shaft; thus, it is manifest the motion is reversed with great facility by changing the position of the horizontal axle so that the wheel upon it may be driven by the two cog-wheels alternately. A wheel and pinion working at the other end of the horizontal axle will communicate the motion to the dressing-machines.

Mr. W. Dryden, Mr. Lloyd's foreman, employed in the erection of this mill, suggests that a nearly similar mode may be advantageously adopted in working the dressing-machines in wind-mills: three wheels, all of different diameters, may be employed, two of them, as A and C, turning upon a vertical shaft, and the third, B, upon an inclined one. In fig. 10. pl. XXXV. the wheels A and B are shown in gear, while C is out: and if A be struck out by some such contrivance as is adopted with regard to the first cog-wheel and wallowers (fig. 5. 6.), C would come in contact with B, while A would be free, and so communicate a motion to B the reverse way. By this contrivance it would be easy, when the winds are strong and give a rapid motion to the vertical axle, to bring C to drive B the wheel on the axle of the dressing-machines; and, on the contrary, when the wind was slack, and the consequent motion of the machinery slow, let C be thrown out of gear and the wheel B driven by the larger wheel A, as shown in the figure.

We should have been glad to see adopted in this well-constructed mill a contrivance recommended and pursued by the American millwrights, for raising the ground corn to the cooling-boxes or beaches from which it is to be conveyed into the bolting machine. In this mill, as in all we have seen, the corn is put into bags at the troughs below the mill-stones, and thence raised to the top of the mill-house by a rope, folding upon barrels turned by some of the interior machinery of the mill. In the American method a large screw is placed horizontally in the trough which receives the flour from the mill-stones. The thread or spiral line of the screw is composed of

pieces of wood about two inches broad and three long, fixed into a wooden cylinder seven or eight feet in length, which forms the axis of the screw. When the screw is turned round this axis, it forces the meal from one end of the trough to the other, where it falls into another trough, from which it is raised to the top of the mill-house by means of elevators, a piece of machinery similar to the chain-pump. These elevators consist of a chain of buckets or concave vessels like large tea-cups, fixed at proper distances upon a leathern band, which goes round two wheels, one of which is placed at the top of the mill-house, and the other at the bottom, in the meal-trough. When the wheels are put in motion, the band revolves, and the buckets, dipping into the meal-trough, convey the flour to the upper story, where they discharge their contents. The band of buckets is inclosed in two square boxes, in order to keep them clean, and preserve them from injury.

But it is time to direct our attention,

2. *To tide-mills in which the axle of the water-wheel neither rises nor falls, and in which that wheel is made always to revolve in the same direction.*

A water-wheel of this kind must manifestly, at the time of high-tide, be almost if not entirely immersed in the fluid: and to construct a wheel to work under such circumstances is, obviously, a matter which requires no small skill and ingenuity.

The first persons who devised a wheel which might be turned by the tide, when completely immersed in it, were Messrs. *Gosset* and *de la Deuille*. Their wheel is described by Belidor in nearly the following terms: Suppose GH (fig. 12. pl. XXXV.) to denote the surface of the water at high-tide, the line LM the surface at low water, and that the current follows the direction of the arrow N; the problem is to construct the wheel such that it may always turn upon its axis IK. The figure just referrred to is a profile of an assemblage of carpentry which must be repeated several times along the arbor, according to the length which it is proposed to give to the float-boards; and the planks or plates which compose these floats must be hung to the other parts of the frame by as many joints as are necessary to enable them to sustain the impulse of the water without bending. The sole peculiarity of this wheel consists in hanging upon the transverse beams in the frame-work, by hinges, the planks which are to compose the float-boards; so that they may present themselves in face, as, D, D, D, when they are at the bottom of the wheel, to receive the full stroke of the stream; and, on the contrary, they present only their edges, as at A, A, A, when they are brought towards the summit of the wheel: hence, the water having a far greater effect upon the

lower than the upper parts of the wheel, compels it to revolve in the order of the letters; instead of which, if the float-boards were fixed, as in the usual way, the impulse of the fluid upon the wheel would be nearly the same in all its parts, and it would remain immoveable.

We see, at once, that the boards D, D, D, having moved towards M, then begin to float, as at E, E, E, and more still at F, F, F, but that it is not till they arrive at A, A, A, that they attain the horizontal position; after that, having arrived at B, B, B, they begin to drop towards the beams to which they are hooked, and as soon as they have passed the level of the axle IK, the stream commences its full action upon them, which it attains completely between C, C, C, and E, E, E, and this whether the surface of the water be at GH or at LM; for even in the latter case it is manifest that the float-boards are entirely immersed when in the vertical position PQ. Belidor says he was present at the first trial of such a wheel at Paris, and that it was attended with all the success that could be desired.

A water-wheel has been lately invented by Mr. Dryden, which will work when nearly immersed in water of a flowing tide. Fig. 4. pl. XXXV. is an elevation of this wheel, its upper parts being supposed to stand a foot or two higher than the tide ever rises: the axis of this wheel remains always in one place, and the wheel will work at high water when the head is at B and the tail-water at the dotted line A; it will also perform nearly the same work when the head is at C, and the tail-water level with the bottom of the wheel. The floats are all set at one and the same angle with the respective radii of the wheel, as may be seen in the figure, and are made so as to have an opening of at least an inch between each float and the drum-boarding of the wheel. This opening is intended to prevent the wheel from being impeded by the tail-water; for as the bucket rises out of the water there can be no vacuum formed in it, there being a full supply of air, in consequence of which the water leaves the wheel deliberately. The case is different with regard to wheels made in the common way: for if such are *open* wheels, the floats are made in such a manner as to throw the tail-water if they are immersed any depth in it; or, if they are *close*, the wheel wants proper vent for the air to prevent the formation of a vacuum in the rising bucket, or what is called by the miller "sucking up the tail-water." At D is planking made circular, to fit the wheel pretty close for rather more than the space of two floats, so as to confine the water nearly close to the wheel. E, F, G, H, are sluices which are all connected together by the iron-bar I, and lifted with the assistance of a wheel, two pinions, and a winch, the first pinion

working into the rack K: these sluices are merely for stopping the wheel when occasion requires, although one might be sufficient to supply the wheel. The rings of this wheel may be made either of cast-iron or of wood; the floats may be iron plates riveted together. The flanches on the arms of the wheel exhibited in the sketch are intended to facilitate the fixing of the first cog-wheel: the ring of the wheel may be fixed to the flanches at the extremity of the arms, and the large flanch made fast to the axle will receive the middle part of the wheel.

Fig. 4. pl. XXXVII. is a plan of the house in which either of the two latter wheels may be fixed, showing in what manner the water may be conveyed always on one side of the wheel by the assistance of the four gates A, B, C, and D. When the mill is working from the river, A and B are open, the arrows point out the way the water runs from the river to the basin; and the dotted lines, on the contrary, the course from the basin to the river, when A, B, are shut, and C, D, opened. These gates are made to turn on an axle, which is about six inches from the middle of the gate: and on the top of the axle is a half-wheel: by some crane-work connected to it, the gate can be opened or shut at pleasure: when a head of water passes against the gates, they will open great part of the way of themselves, by only letting the catches that keep them shut be lifted out of their place. X, Y, are two knees of cast iron, to support the posts that the gates are fixed to. The walls of the building are represented at *a*, *b*, *c*, and *d*.

The reader will now be able to form an estimate of the comparative value and ingenuity of the two kinds of tide-mills here described. The simplicity of construction of the wheels of Gosset, de la Deuille, and Dryden, recommend them strongly; but we entertain some doubts of their being completely successful in practice: had the curious wheel with the folding-gates, &c. figs. 5. 6. pl. XXXV. been placed with its axle perpendicular instead of parallel to the course of the river, the water might then have always been admitted to act upon the same side of it, and the hydrostatic pressure would have operated as completely in lowering it continually during the time of ebb, as in raising it continually during the rising of the tide: thus, as appears to us, would the labour of a man be saved, who according to the present construction must attend the water-wheel; and all the additional apparatus now requisite to shift the spur-wheels would at the same time be saved, and a consequent diminution of original expense.

We shall annex to this article a description of an improvement on tide-mills, to make them work as well at high and low water as any other time of tide, by Mr. John Isaac Hawkins.

Mr. Hawkins's improvement consists in having a reservoir to be filled by the tide at high water, through a canal furnished with a valve-sluice, so as to let the water pass into the reservoir, but not to go back again the same way. The content of this reservoir or upper pond is to be conveyed by the usual means over or under a water-wheel, and then received by another reservoir or lower pond, where it is retained till the time of low water, when it opens another valve-sluice, and discharges itself into the river or sea, from whence it was received. Upon this principle, a constant fall of water from the upper into the lower pond is obtained by means of the rising and falling of the tide, and that without requiring any person to attend it; for, whenever the water is higher in the river or sea than in the upper pond, it will open the sluice and fill the pond; and whenever it is lower in the river or sea than in the lower pond, the weight of water in the latter will open the lower sluice.

To adopt this plan in places where the general level of the land is about half way between high and low water, nothing more would be necessary than to dig out the lower pond, and with the same earth make an embankment, which will form the upper.

The same principle may be applied to those tide-mills already in use, that work forwards and backwards. Let two small ponds, an upper and a lower, be dug, each capable of holding water enough to turn the mill about two hours: these may be called auxiliary ponds, and the original one the main pond. Let there be two channels for the water to go into the main pond, one under the water-wheel, and the other merely to fill the pond; and let there be a communication from the water-wheel channel to each of the auxiliary ponds, as well as from these to the river or sea. Then may the motion of the water-wheel be always kept up with due force: for, during the rising of the tide, and until within an hour of high water, the current would be under the water-wheel and into the main pond as usual; but the force of the tide then slackening, the communication between the water-wheel channel and the main pond must be shut, and the current, after passing the wheel, must be turned into the lower auxiliary; at the same time the tide must be admitted into the main pond through the other channel, and the upper auxiliary likewise filled. By the time the lower pond is full the tide will be running down strong enough to admit of the wheel being turned backwards, in the ordinary way, by the contents of the main pond passing back through the water-wheel channel. This will continue until about an hour before low water, when the contents of the upper auxiliary pond must be carried under the wheel, and then discharged into the river

or sea, and the main and lower auxiliary ponds allowed to empty themselves.

We willingly give place to this improvement in the formation of reservoirs for tide-mills, because, notwithstanding the great utility and advantage of this kind of machinery, but little has been published relative to it in this country. (*Retrospect*, No. 15.)

TURNING, the art of forming hard bodies, as wood, ivory, iron, into a round or oval shape by means of a machine called a *lathe*. This art was well known to the ancients, and seems to have been carried by them to a very great degree of perfection; at least, if we believe the testimony of Pliny and several other authors, who tell us, that those precious vases enriched with figures in half-relief, which still adorn our cabinets, were turned on the lathe.

The art of turning is of considerable importance, as it contributes essentially to the perfection of several other arts. The architect uses it for many ornaments both within and without highly-finished houses. The mathematician, the astronomer, and the natural philosopher, have recourse to it, not only to embellish their instruments, but also to give them the necessary dimension and precision: and it is an art absolutely necessary to the goldsmith, the watchmaker, the joiner, and the smith.

Turning is performed by the lathe, of which there are various kinds, and several instruments, as gouges, chisels, drills, formers, screw-tails, used for cutting what is to be turned into its proper form as the lathe revolves. The most simple kind of lathe is a well-known instrument, and need not be described here: the improved lathes manufactured by Messrs. *Maudslay* and *Field*, of Lambeth Marsh, are both curious and useful. Mr. *J. Farey*, jun. who took the drawings of these elegant specimens of mechanical ingenuity, has accompanied them with a description, nearly as below. A (pl. XXXVI. fig. 1.) is the great wheel, with four grooves on the rim; it is worked by a crank B and treadle C, in the common way; the catgut which goes round this wheel passes also round a smaller wheel D, called *the mandrel*, which has four grooves on its circumference of different diameters for giving it different velocities, corresponding with the four grooves on the great wheel A. In order to make the same band suit, when applied to all the different grooves on the mandrel D, the wheel A can be elevated or depressed by a screw *a*, and another at the other end of the axle; and the connecting-rod c can be lengthened or shortened by screwing the hooks at each end of it further out of, or into it. The end M, fig. 2., of the spindle of the mandrel D, is pointed, and works in a hole in the end of a

screw, put through the standard E, fig. 1.; the other end of the bearing F, fig. 2. is conical, and works in a conical socket in the standard F, fig. 1. so that by tightening up the screw in E, the conical end F may at any time be made to fit its socket: the puppet G has a cylindric hole through its top to receive the polished pointed rod *d*, which is moved by the screw *e*, and fixed by the screw *f*; the whole puppet is fixed on the triangular prismatic bar H, by a clamp, fig. 8., the two ends of which, *a*, *b*, are put through holes, *b*, in the bottom of the puppet under the bar, and the whole is fixed by the screw *c* pressing against it: by this means, the puppet can be taken off the bar without first taking off the standard I, as in the common lathes: and the triangular bar is found to be far preferable to the double rectangular one in common use. The rest J is a similar contrivance; it is in three pieces; see figs. 3. 4. and 5. Fig. 4. is a piece, the opening (*a*, *b*, *c*,) in which is laid upon the bar H, fig. 1.; the four legs *dddd* of fig. 5. are then put up under the bar (into the recesses in fig. 4. which are made to receive them) so that the notches in *dddd* may be level with the top of fig. 4., the two beads *ef* in fig. 3. are then slid into the notches in the top of *dddd*, fig. 4. to keep the whole together; the groove *i* is to receive a corresponding piece on *ef*, fig. 3., to steady it; the whole of fig. 3. has a metallic cover, to keep the chips out of the grooves. It is plain, that by tightening the screw *h* in the bottom of fig. 4. the whole will be fixed and prevented from sliding along the bar H, and fig. 3. from sliding in a direction perpendicular to the bar; the piece *l*, fig. 3., on which the tool is laid, can be raised or lowered at pleasure, and fixed by the screw *m*. On the end *n* of the spindle P, figs. 1. and 2., is screwed occasionally an *universal* CHUCK for holding any kind of work which is to be turned (see fig. 6.). A is the female screw to receive the screw *n*, fig. 1.; near the bottom of the screw A is another screw BB, which is prevented from moving endways by a collar in the middle of it fixed to the screw A; one end of the screw BB is cut *right handed*, and the other *left handed*; so that by turning the screw one way, the two nuts EF will recede from each other, or by turning it the contrary way, they will advance towards each other: the two nuts EF pass through an opening in the plate C, and project beyond the same, carrying jaws like those of a vice, by which the subject to be turned is held.

For turning faces of wheels, hollow work, &c. where great accuracy is wanted, Mr. *Maudslay* has contrived a curious apparatus which he calls a *slide-tool*, represented by fig. 7., where EEE is the opening to receive the bar H, fig. 1., and it is fixed by the clamp, fig. 8. as before described: the tool for

cutting, &c. is fixed in the two holders *bb* by their screws; these holders are fastened to a sliding-plate *a*, which can be moved backwards and forwards by the screw *c*, causing the tool to advance or recede; fig. 9. represents the under side (turned upward) of the part AA, in which the screw *c* is seen fixed at each end, and the nut *d*, which is attached to the underside of the plate *a*, working upon it. When it is necessary, as in the turning of the inside of the cones, &c. that the tool should not be parallel to the spindle P, the screw *e* and another similar one behind must be loosened, the tool set at the proper angle, and then be screwed tight again. In order to make the piece AA move truly when it is turned round, there is a hole *f*, fig. 9. to receive a knob *g*, fig. 14., upon the plate B, which acts as a centre, and keeps it in its place: there are three holes on each side in the plate B, fig. 12., to put the screw *e* in at different times, thus giving to the tool a greater range than the circular openings s s will admit. The part EEEE, represented separately, and inverted in fig. 10. is of cast iron, and has a screw *h* working in it similar to fig. 9.; the nut of this screw is attached to the bottom of the slide H, fig. 11., at *t*, which slides in the groove *i*, figs. 7. and 10.; at one end of it is a box containing a screw *m*, to be hereafter described, and at the other is a frame of brass KK. Near the same end of the slide is a pin L, projecting above the plate, which is put through an opening, J in fig. 12., to steady it, while the other end, C of fig. 12., is put through an opening M in the box D, fig. 11. In the part C is an oblique slit *ll* to receive a stub which projects from the bottom of the nut *n*, worked by the screw *m*, fig. 11.: by this arrangement it is obvious that if the screw *m* is worked, the stub of the nut *n*, acting against the slide of the slit *ll* as an inclined plane, will move it either backwards or forwards through the opening M; a metal cover *r*, fig. 14., is occasionally put over the opening for the nut *n* and screw *m* to prevent the chips from falling in. Near the four corners of the frame, fig. 12., are four small projections *oooo*, with inclined sides, which fit into the four openings *pppp* of figs. 13. and 7.; these openings are cut out in two brass plates, which are screwed on at right angles to the plates BB, figs. 7. and 13.; the ends *qqqq* of these plates slide between the edges of the frame KK and the box D, so as to prevent any other motion than a vertical one.—When the *slide-tool* is used, the puppet G is to be removed or pushed back further from F, and the tool is put upon the bar H, fig. 1., and fixed in the place of the rest J by the clamp fig. 8.; the distance from the centre *n* is adjusted by the screw *h*, which moves the slide, fig. 11. in the grooves *i*, figs. 7. and 10. with the whole apparatus upon it: by the screw *m*, figs. 7. and 11., as before described, the slide, fig. 12., may be moved in a direction perpendicular to the

bar H, fig. 1.; and its projections *oo* acting against the slits *pp*, figs. 7. and 13., as inclined planes, will raise or lower the plate B as is required.

The tool, which has been before fixed in the holders *bb*, can be set at the proper angle, by loosening the screw *e*, as previously described: and, lastly, the tool with the holders and slider *a* can be advanced or withdrawn by working the screw *e*. The nuts of the screws *c* and *h*, fig. 7., are not screwed fast to the sliding plates, but are held by two pins *t*, fig. 11., which fit into grooves *u*, fig. 10., in each side of the nut: by these means the sliding plate can at any time be taken out by only unscrewing one of the brass sides from the groove *i*, without taking out the screw and nut. In order to make the grooves always fit their slides, the two pieces of brass *yy*, fig. 7., which compose the sides of the groove, have elliptic holes for their screws *v*, so as to admit, when the screws are slackened, of being pushed inwards by the screws *w*, which work in a lump of metal cast with the part AA.

The large lathes which Mr. Maudslay uses in his manufactory, instead of being worked by the foot, as represented in fig. 1., are worked by hand; the wheel and fly-wheel which the men turn works by a strap on another wheel, fixed to the ceiling directly over it; on the axis of this wheel is a larger one, which turns another small wheel or pulley, fixed to the ceiling, directly over the mandrel of the lathe; and this last has on its axis a larger one which works the mandrel D, by a band of catgut. These latter wheels are fixed in a frame of cast-iron, moveable on a joint; and this frame has always a strong tendency to rise up, in consequence of the action of a heavy weight; the rope from which, after passing over a pulley, is fastened to the frame: this weight not only operates to keep the mandrel-band tight, when applied to any of the grooves therein, but always makes the strap between the two wheels on the ceiling fit. As it is necessary that the workman should be able to stop his lathe, without the men stopping who are turning the great wheel, there are two pulleys or rollers (on the axis of the wheel over the lathe), for the strap coming from the other wheel on the ceiling; one of these pulleys, called the *dead pulley*, is fixed to the axis and turns with it, and the other which slips round it is called the *live pulley:* these pulleys are put close to each other, so that by slipping the strap upon the *live pulley*, it will not turn the axis; but if it is slipped on the other it will turn with it: this is effected by an horizontal bar, with two upright pins in it, between which the strap passes. This bar is moved in such a direction as will throw the strap upon the live pulley, by means of a strong bell-spring; and in a contrary direction it

is moved by a cord fastened to it, which passes over a pulley, and hangs down within reach of the workman's hand: to this cord is fastened a weight, heavy enough to counteract the bell-spring, and bring the strap up to the dead pulley, to turn the lathe; but when the weight is laid upon a little shelf, prepared for the purpose, the spring will act and stop it.

Mr. Maudslay has likewise some additional apparatus for cutting the teeth of wheels, in which the face of the mandrel D, fig. 1., has seventeen concentric circles upon it, each divided into a different number of equal parts, by small holes. There is a thin stop, *x*, fig. 1., which moves round on a screw, fixed in the standard F: this stop is made of thin steel, and is so fixed, that when it is turned up, and its point inserted into any of the divisions of the mandrel, it will have a sufficient spring to keep it there: the wheel to be cut is fastened, by means of a chuck, to the screw *n*, and after it has been turned, and brought to the proper shape, the rest J is to be taken away, and the slide-tool substituted: a square bar is then put into the two holders, *bb*, fig. 7.; this bar has two branches for holding the ends of a spindle, near one end of which is a pulley, and at the other are four chisels, fixed perpendicularly into the spindle for cutting out the teeth (instead of the circular saw commonly used): the pulley is turned (with the intervention of several wheels to augment the velocity) by the same great wheel as the lathe, with 7300 revolutions per minute; the mandrel is then fixed by the stop *x*, fig. 1., and the cutter advanced towards the wheel, by the screw *c*, fig. 7. When it has cut that tooth, the cutter is withdrawn, and the mandrel turned to another division, and a tooth is cut again as before. At that part of the frame of the cutting-spindle where the bar which is fixed in the holders of the slide-tool connects with the two branches there is a joint, by which the cutting-spindle can be set in an inclining position, for cutting oblique teeth like those which are to work with an endless screw. The great velocity with which this spindle turns soon generates, by friction and resistance, a degree of heat sufficient to expand it very sensibly; but this ingenious mechanist, foreseeing such a circumstance, has judiciously compensated for it in his construction, by making the spindle so short as to play loosely in its sockets at the commencement of the motion; but after a few seconds the expansion is such as to cause the whole to fit together as it ought to do, and the work of cutting to proceed with accuracy and safety.

Another skilful mechanic, Mr. *Smart*, of Ordnance Wharf, Westminster, whose chimney-cleansers and saws have been no-

ticed in earlier parts of this volume, has made some very useful improvements in the art of turning, and particularly has struck out a simple method of turning cylinders and cones, in wood. The figures to illustrate his turning machinery are given in pl. XXVI. (figs. 3, 4.), where the legs or stiles L, the puppets A, B, the cheeks *o*, *o*, the pikes and screws, M, N, R, with the handle D, are but slightly varied from the usual construction. Round the mandrel E passes a band F, F′, which also encompasses a large wheel not shown in the figure; and when this large wheel is turned round with moderate swiftness, it communicates a rapid velocity to the mandrel E, and the long piece of wood G, which is proposed to be made cylindrical. This piece is previously hewn into an octagonal form. The cutting-frame H contains a sharp iron tool, which is to answer the purpose of the common turning-gouge, and which is fitted into the frame so as to project a little beyond its inner part, after the manner of a carpenter's plane-iron for round or ogee work. Then, while the piece G is turning swiftly round by a man working at the great wheel, another man pushes the frame H gently on from L towards M, the lower part of that frame fitting between the cheeks *o*, *o*, and sliding along between them. By this process, the piece G is reduced to a cylinder, moderately smooth; and, in order to render the smoothness as complete as need be, a second cutter, and its frame I, adapted to a rather smaller cylinder than the former, is pushed along in like manner from L to M. This operation may be performed with such speed, that a very accurate cylinder of 6 feet long, and 4 inches diameter, may be fixed to the lathe and turned in much less than a minute.

Mr. Smart turns a conical end to one of these cylinders with great facility, by means of a cutting-blade fixed in an iron hollow conical frame K, the smaller end of which admits the pike from the screw S (fig. 4.), to which one end of the cylinder G is attached: as the cylinder turns rapidly round, the cutter K is conducted gently along it by means of the hollow frame, and soon gives the conical shape to the end of the cylinder, as required.

Excellent lathes, with considerable improvements, are likewise made by Messrs. Holtzapffel and Deyerlein, 118, Long Acre.

The following improvement in the construction of the lathe is extracted from that useful publication the *Mechanic's Magazine*.

Figure 2. pl. XLIV. is the appearance of the lathe endwise; C represents one of two pieces, which are fixed to the back-bed of the lathe; F is a lever, moveable on the centre *o*, which lever has a piece cut out of the end, to admit the extra pulley D, which must, to allow the band to pass without rubbing, be

placed so as to stand in winding with the pulley on the mandrel, as shown by *d*, fig. 2; the lever F is furnished with hooks, on which the weight G is hung, according to the nature of the work. It would improve the plan if the grooves in the mandrel pulley, instead of being angular, were turned rather flat at the bottom.

Fig. 3. will be readily understood, as the same letters denote the same parts as in fig. 2.

AA are beds of the lathe; C, the mandrel pulley; B, the large wheel.

WATCH, a small portable machine for measuring time; having its motion commonly regulated by a spiral spring. Perhaps, strictly speaking, watches are all such movements as *show* the parts of time; as clocks are such as *publish* them, by striking on a bell, &c. But commonly, the term watch is appropriated to such as are carried in the pocket; and clock to the large movements, whether they strike the hour or not.

Spring or *Pendulum* WATCHES stand pretty much on the same principle with pendulum clocks. For if a pendulum, describing small circular arcs, make vibrations of unequal lengths, in equal times, it is because it describes the greater arc with a greater velocity; so a spring put in motion, and making greater and less vibrations, as it is more or less stiff, and as it has a greater or less degree of motion given it, performs them nearly in equal times. Hence, as the vibrations of the pendulum had been applied to large clocks, to rectify the inequality of their motions; so to correct the unequal motions of the balance in watches, a spring is added, by the isochronism of whose vibrations the correction is to be effected. The spring is usually wound into a spiral, that, in the little compass allotted it, it may be as long as possible; and may have strength enough not to be mastered, and dragged about, by the inequalities of the balance it is to regulate. The vibrations of the two parts, viz. the spring and the balance, should be of the same length; but so adjusted, as that the spring, being more regular in the length of its vibrations than the balance, may occasionally communicate its regularity to the latter.

Striking WATCHES are such as, besides the proper watch-part for measuring of time, have a clock-part for striking the hours, &c.

Repeating WATCHES are such as by pressing a spring, &c. repeat the hour, quarter, or minute, at any time of the day or night. This repetition was the invention of Mr. Barlow, and first put in practice by him in larger movements or clocks about the year 1676. The contrivance immediately set the other artists to work, who soon contrived divers ways of effecting the

same: but its application to pocket watches was not known before king James the Second's reign; when the ingenious inventor above mentioned, having directed Mr. Thompson to make a repeating watch, was soliciting a patent for the same. The talk of a patent engaged Mr. Quare to resume the thoughts of a like contrivance, which he had had in view some years before: he now effected it; and being pressed to endeavour to prevent Mr. Barlow's patent, a watch of each kind was produced before the king and council; upon trial of which, the preference was given to Mr. Quare's. The difference between them was, that Barlow's was made to repeat by pushing in two pieces on each side the watch-box; one of which repeated the hour, and the other the quarter: whereas Quare's was made to repeat by a pin that stuck out near the pendant, which being thrust in (as now it is done by thrusting in the pendant itself), repeated both the hour and quarter with the same thrust.

Of the Mechanism of a WATCH, properly so called. Watches, as well as clocks, are composed of wheels and pinions, and a regulator to direct the quickness or slowness of the wheels, and of a spring which communicates motion to the whole machine. But the regulator and spring of a watch are vastly inferior to the weight and pendulum of a clock, neither of which can be employed in watches. Instead of a pendulum, therefore, we are obliged to use a balance (pl. XXXIII. fig. 1.) to regulate the motion of a watch; and a spring (fig. 2.) which serves instead of a weight, to give motion to the wheels and balance.

The wheels of a watch, like those of a clock, are placed in a frame formed of two plates and four pillars. Fig. 3. represents the inside of a watch, after the plate (fig. 4.) is taken off. A is the barrel which contains the spring (fig. 2.); the chain is rolled about the barrel, with one end of it fixed to the barrel A, (fig. 5.), and the other to the fusee B.

When a watch is wound up, the chain which was upon the barrel winds about the fusee, and by this means the spring is stretched; for the interior end of the spring is fixed by a hook to the immoveable axis about which the barrel revolves; the exterior end of the spring is fixed to the inside of the barrel, which turns upon an axis. It is therefore easy to perceive how the spring extends itself, and how its elasticity forces the barrel to turn round, and consequently obliges the chain which is upon the fusee to unfold and turn the fusee: the motion of the fusee is communicated to the wheel C (fig. 5.); then, by means of the teeth, to the pinion *c*, which carries the wheel D; then to the pinion *d*, which carries the wheel E; then to the pinion *e*, which carries the wheel F; then to the pinion *f*, upon which is the

balance-wheel G, whose pivot runs in the pieces A called the *potance*, and B, called a *follower*, which are fixed on the plate, fig. 4. This plate, of which only a part is represented, is applied to that of fig. 3. in such a manner that the pivots of the wheels enter into holes made in the plate, fig. 3. Thus the impressed force of the spring is communicated to the wheels; and the pinion *f* being then connected to the wheel F, obliges it to turn (fig. 5.). This wheel acts upon the palettes of the verge 1, 2 (fig. 1.), the axis of which carries the balance HH (fig. 1.). The pivot I, in the end of the verge, enters into the hole *c* in the potance A (fig. 4.). In this figure the palettes are represented; but the balance is on the other side of the plate, as may be seen in fig. 6. The pivot 3 of the balance enters into a hole of the cock BC (fig. 7.) a perspective view of which is represented in fig. 8. Thus the balance turns between the cock and the potance *c* (fig. 4.) as in a kind of cage. The action of the balance-wheel upon the palettes 1, 2 (fig. 1.) is the same with what we have described with regard to the same wheel in the clock; *i. e.* in a watch, the balance wheel obliges the balance to vibrate backwards and forwards like a pendulum. At each vibration of the balance a palette allows a tooth of the balance-wheel to escape; so that the quickness of the motion of the wheels is entirely determined by the quickness of the vibrations of the balance; and these vibrations of the balance and motion of the wheels are produced by the action of the spring.

But the quickness or slowness of the vibrations of the balance depends not solely upon the action of the great spring, but chiefly upon the action of the spring *a*, *b*, *c*, called the *spiral spring* (fig. 9.), situated under the balance H, and represented in perspective (fig. 6.). The exterior end of the spiral is fixed to the pin *a* (fig. 9.). This pin is applied near the plate in *a* (fig. 6.); the interior end of the spiral is fixed by a peg to the centre of the balance. Hence if the balance is turned upon itself, the plates remaining immoveable, the spring will extend itself, and make the balance perform one revolution. Now, after the spiral is thus extended, if the balance be left to itself, the elasticity of the spiral will bring back the balance, and in this manner the alternate vibrations of the balance are produced.

In fig. 5. all the wheels above described are represented in such a manner, that it may be easily perceived at first sight how the motion is communicated from the barrel to the balance.

In fig. 10. are represented the wheels under the dial-plate by which the hands are moved. The pinion *a* is adjusted to the force of the prolonged pivot of the wheel D (fig. 5.), and is called a *cannon pinion*. This wheel revolves in an hour. The end

of the axis of the pinion *a*, upon which the minute hand is fixed, is square; the pinion (fig. 10.) is indented into the wheel *b*, which is carried by the pinion *a*. Fig. 11. is a wheel fixed upon a barrel, into the cavity of which the pinion *a* enters, and upon which it turns freely. This wheel revolves in twelve hours, and carries along with it the hour-hand.

Such in brief is the general mechanism of a watch: to treat the subject to the extent its importance demands would require a volume: some parts of the construction are further explained under the words BALANCE and SCAPEMENT in this volume.

Mr. Elliot, of Clerkenwell, has lately invented a very simple *repeating* watch, in which the motion is performed with much fewer parts than in the usual construction, by which means he is enabled to reduce the price so low as eight guineas for a good repeater on this principle, or to add the repeating-work to another watch for three.

The method by which this repeater is so much simplified is by the use of a single part, so contrived as to perform the operations of several: this is a flat ring, or centreless wheel, of nearly the same diameter as the watch, supported in its place, so as to admit of circular motion, by four grooved pulleys placed round its external circumference, in the same manner as the part in common clocks which denotes the moon's age. This part is put in motion by turning the pendant, whose extremity is formed into a small vertical wheel, which works in teeth cut on the external part of the flat ring for almost a third of its circumference. The lower part of the ring contains the pins, at right angles to its face, which lift the hammers for striking the hours and quarters; the internal part of the ring contains indentations of regularly increasing depths, which receiving the tails of the levers whose other extremities are pressed by their springs against the hour-snail and the quarter-snail, is by them prevented from moving beyond a certain degree proper for the time: after the pendant is turned, the ring is brought back to its first position, by a box-spring, round which a fine chain is coiled, whose extremity is connected with the inner part of the ring.

By turning the pendant to the left the hour is struck, and by turning it to the right the quarters are repeated; and the returning spring just mentioned is made to operate in both directions, by its chain passing between two little pulleys, which on either side convert the direction of the chain to the line of traction of the spring.

Hence it is evident this single flat ring performs all the following operations.

1. It receives the motion for striking the hour from the pendant.
2. — The same for striking the quarters.
3. It carries the pins, or teeth, which lift the hour-hammer.
4. — The same for the quarter-hammer.
5. It contains the indentations by which the hour-snail operates on it by its lever.
6. — The same, by which the quarter-snail operates on it.
7. It carries the part that recoils the movement which tells the hour to its first position.
8. It carries the part, for the same purpose, for the quarter-movement.
9. It contains a cavity, which moves over a fixed pin, that prevents the pendant from turning it too far.

In this ring, the same parts, in three instances, are made to perform double operations, by which simplicity of construction is advanced, apparently to its greatest extent.

For other constructions the reader may consult the *Pantologia*.

WATCHMAN's Noctuary, the name given to an instrument lately contrived to remedy a great defect in an important branch of the police of great cities, that of *night-watching*. Every twenty-four hours furnishes some instance of the inefficacy of the present system, by the depredations which have been committed in the night, or by the fatal accidents which occur from a neglect of giving families timely warning in cases of sudden fires. A respectable magistrate (Samuel Day, Esq. of Charter-house, Hinton, Somersetshire) has directed his attention to the application of a mechanical check upon the diligence and regularity of watchmen, labourers, and all other classes of men whose duty requires that they should attend at certain places at appointed times: the instrument he has invented for this purpose he calls a *Watchman's noctuary*, or *Labourer's Regulator*.

The invention consists principally of a large horizontal wheel, which is moved uniformly round every 12 hours by clock-work. The upper side of this wheel is divided by two circles, one within the other; the outer one, or periphery, having the hours and quarters marked on it, which may be called the lateral side; the inner circle having also a dial, which may be called the vertical one. The space between these circles or dials is divided into cells, each cell corresponding with a quarter or half-hour of the different hours marked on the dials; and if thought proper, the cells might be so multiplied, as that each would correspond within a period of five minutes. Such

is the upper side of the horizontal wheel, which may be made of copper or tin, or various other materials, and is about 9 inches in diameter. The under side of the same has a brass wheel with teeth, diameter $3\frac{1}{4}$ inches, fixed to its central part; the teeth of which, letting in with those of a smaller wheel or pinion, give motion in consequence to the large horizontal wheel (of which it forms a part) by the motion it receives from the pinion. This pinion being set in motion by the common clock-work and a weight or spring, the revolution of the horizontal wheel is completed once in twelve hours, and thus, regularly going round, will at all times show the time of day or night. As it moves round it carries the cells above-mentioned under a kind of chink, just large enough to receive a token of about the size of a farthing. This chink sinks down from an external brass box, which is sufficiently large to admit a man's fingers to drop in the token by an external aperture or mouth of the chink, the token being directed perpendicularly through this chink into such cell as is immediately under it, and which must correspond with the time of night or day. The head of the case of the machine has double doors in front; the outward door covers the whole face together, leaving a sufficient space above the horizontal wheel for examining the tokens and taking them from the cells, or for removing the wheel when necessary. A smaller door opens in this large one upon the brass box above mentioned, the opening of which belongs solely to the watchman, or such other person as may be required to use the same, for the purpose of seeing the time and dropping his tokens, a minute-dial also being placed under the hour-index. If it be found more convenient, a common dial-plate, to show the hours and minutes, may be placed instead of the minute-dial. The great outer door first mentioned is to be opened only by the inspector or examiner of the tokens, and ought to be well secured; but, for greater safety, both against thieves and weather, there is an inside door, in which the fore-mentioned brass box is fixed; and this inner door being opened, throws into view the horizontal wheel, for the purpose just specified. These are the essential parts of the invention: the different appendages may be variously modified.

One such instrument as this being placed at each end of a watchman's round, it will be ascertained how the man continued his movements through the night, to a nicety of 10 minutes (or less, if required) at any period of the watch; and the slightest irregularity or omission will be detected the next morning by the person whose office it shall be to open the machine. No trick or fraud on the watchman's part can counteract the move-

ment of the horizontal wheel comprising the cells into which the tokens are to be dropped; each cell is, by this contrivance, like time itself, irrevocable when past: the watchman has no command over it, and the whole will be a kind of speaking witness of his diligence and fidelity in going his rounds, answering the next morning to the exact periods he either was or ought to have been there.

By this means the calls of the watchmen, which were only instituted for the purpose of his giving notice of being on his duty, will be superseded; and a considerable expense of animal exertion will be saved to the individual, which might better be converted into that of going his rounds twice, where he now only goes once. Warnings to the nightly thief of timely attack or retreat will likewise be taken away; and if instead of an open, the watchman was to carry a dark, lantern, the robber would have no security whatever in calculating the moment of his depredation, and might be detected in the very outset of his attack, as the slightest sound would alarm the watchman walking in silence, and not drowning distant noise by that of his own voice.

The same machine will answer in custom-houses, ware-houses, banking-houses, manufactories, bleaching-grounds, and every place where watching or other attendance, to be useful, must be exact; even sentinels on military duty might be required to leave tokens as memorials of their vigilance.

Mr. Day has, we understand, obtained the usual patent for securing to himself the right of making and selling this instrument; yet surely not to the exclusion of others invented for the same purpose: for the late Marquis of Exeter informed the public more than twenty years ago, through the medium of Nicholson's Philosophical Journal, that a clock for a similar purpose had been invented by Messrs. Boulton and Watt of Birmingham, which costs no more than thirty shillings. His lordship had then had two of them at Burleigh-Hall more than four years; and he gives the following description of them: "They go eight days, and have a face like a clock, but do not strike. The dial goes round and the hour-finger is fixed: round the edge of the dial are moveable iron pins, corresponding with the quarters in each hour. A small hammer placed behind the hour-finger, when moved downwards, pushes into the dial one of the pins which happens to be under it at the time, which pin remains so abased until the dial nearly returns to the same place, when by an inclosed plane the pin is raised up into its first position. This gives time to have the machine examined in the morning, to see how many pins have been struck, and at what

time they were pushed downwards. The hammer is moved by the pulling of a chain with a handle, like house-door bells, which, by cranks and wires, is attached to it. I have one in my library; the handle is out of doors. The other machine is placed in a building at the other end of my premises."

WATER-MILLS, the general term by which all kinds of mills which have a stream of water for their first mover are designated. The term is also sometimes applied to machines driven by wind, for the purpose of draining water out of fen lands; but it is with more propriety confined to the preceding acceptation.

It is not our intention in the present article to enter minutely into the description of the various kinds of machinery driven by water as an active power, but to confine ourselves to a few general remarks upon the construction of that part only which is essential to water-mills, the *water-wheel:* for the axis of this wheel may be employed to transmit the force impressed upon it to any species of machinery. A concise view of the theory of water-wheels, together with a tolerably copious statement of the experiments and results of Smeaton, have been laid before the reader in book iv. of our first volume; we propose now to present some observations on their shape, magnitude, and velocity.

The most general division of water-wheels is into two kinds, resulting from the manner in which the fluid is made to act: when water is made to act by its weight, it is delivered from the spout as high on the wheel as possible, that it may continue long to press it down; but when it is made to *strike* the wheel, it is delivered as low as possible, that it may have previously acquired a great velocity: thus are the wheels said to be *overshot* or *undershot.* The four kinds of wheels mentioned in art. 467. vol. i. belong, in fact, to one or other of these general divisions.

1. An *overshot-wheel* is nothing but a frame of open buckets so disposed round the rim of a wheel as to receive the water delivered from a spout in such a manner that one side of the wheel is loaded with water while the other is empty: of consequence the loaded side must descend; and by this motion the fluid runs out of the lower buckets, while the empty buckets of the rising side of the wheel, in their turn, come under the spout, and are filled with water. A slight inspection of the figure of an overshot water-wheel, in plate XVIII. of our first volume, will convince the student of the impossibility of constructing the buckets so as to remain completely filled with water till they reach the bottom of the wheel: indeed, if the buckets are formed by partitions directed to the axis of the wheel, the whole water must be run out by the time that they have de-

scended to the level of the axis; and, of consequence, there must be a great diminution in the mechanical effect of the wheel. Millwrights have, therefore, turned their chief attention to the determination of a form for the buckets which shall enable them to retain the water along a great portion of the circumference of the wheel. It would require much more room than we can assign to this article, to describe half the contrivances which have been proposed: we shall therefore only mention one or two of the best, as described by Dr. Robison in the Encyclopedia Britannica.

In fig. 11. pl. XXXII. AM represents part of the shrouding or ring of buckets of an overshot-wheel which has 40 buckets. The form of one of these buckets is shown by GOFABCD; in which the sole of one bucket AF should be $\frac{6}{5}$ of AE the depth of the shrouding, and the shoulder AB of the bucket should be one half of AE. The arm BC of the bucket must be so inclined to the shoulder AB that HC perpendicular to AHF at H may be $\frac{5}{6}$ of AE; and the wrest (or probably *wrist*) of the bucket CD must be so inclined to BCn, the direction of the arm, that Dn may be about $\frac{1}{5}$ of En.

From this construction it follows, that the area HABC is very nearly equal to DABC: so that the water which will fill the space HABC will all be contained in the bucket when it shall come into such a position that AD is a horizontal line; and the line AB will then make an angle of nearly 35° with the vertical, or the bucket will be 35° from the perpendicular passing through the axis of motion. If the bucket descend so much lower that one-half of the water runs out, the line AB will make an angle of about 24°$\frac{1}{2}$ with the vertical. Therefore the wheel, filled to the degree now mentioned, will *begin* to lose water at about $\frac{1}{5}$ of the diameter from the bottom, and *half of the water will be discharged* from the lowest bucket about $\frac{1}{24}$ of the diameter further down. Had a greater proportion of the buckets been filled with water when they were under the spout, the discharge would have begun at a greater height from the bottom, and a greater portion of the whole fall of water would be lost. The loss by the preceding construction is less than $\frac{1}{10}$th (supposing the water to be delivered into the wheel quite at its top), and may be estimated at about $\frac{1}{12}$th; for the loss is as the versed sine of the angle which the radius of the bucket makes with the vertical. The versed sine of 25° is ·18085, nearly $\frac{1}{5}$th of the radius, or $\frac{1}{10}$th of the diameter. Had only $\frac{1}{2}$ of this water been supplied to each bucket as it passes the spout, it would have been retained for 10° more of a revolution, and the loss of fall would have only been about $\frac{1}{1}$ th.

The bucket has been much improved in its construction by

Mr. Robert Burns, at the Cotton Mills of Houston, Burns, and Co. at Cartside, Renfrewshire. This ingenious millwright divides the bucket by a partition *Bm*, concentric with the sole and rim, and of such an altitude as to make the inner and outer portions of the bucket of nearly equal capacity. It is justly observed by Dr. Robison, that Mr. Burns's principle is susceptible of considerable extension, and, when the practice of making the water-wheel of iron is adopted, he recommends the use of two or more partitions; for such a series of partitions, though each should be very thin, will contribute much to the general firmness of the whole wheel. In consequence of this contrivance the fluid is longer retained in the descending buckets: and when the supply of water is very scanty, a proper adjustment of the apparatus which regulates the position of the spout will direct nearly all the water into the exterior buckets, and thus, by placing it at a greater distance from the axis, sensibly augment its mechanical energy. The doctor suggests also that the breadth of the buckets, or the rim of the wheel, should be tolerably large, that the quantity of water received from the spout may not nearly fill the bucket: and in order to prevent the air from impeding the rising buckets, or as the watermen term it, the buckets from sucking up the tail-water, he advises that the shoulder or sturt AB of each bucket be perforated with a few holes. As to the spout which conveys the water, it should be considerably narrower than the breadth of the wheel; and, as Dr. Brewster justly remarks, this distance of the spout from the receiving bucket should in general be two, three, or four inches, that the water may be delivered with a velocity a little exceeding that of the rim of the wheel; otherwise the wheel will be retarded by the impulse of the buckets against the stream, and the dashing of the water over would occasion a diminution of power.

With respect to variations in the fall of water, since the active pressure is measured by the pillar of water reaching from the horizontal plane where it is delivered on the wheel, to the horizontal plane where it is spilled by the wheel, it has been concluded that the pressure must be proportional to the wheel; and therefore the water must be delivered as high, and retained as long as possible. This maxim, however, is subject to limitations, and is not perhaps strictly consistent with sound theory. When the fall is exceedingly great, a wheel of an equal diameter becomes enormously big, and extremely expensive. In cases like this, where we are unwilling to lose any part of the force of a fall-stream, the best form of a bucket-wheel is an inverted chain pump.

The velocity of an over-shot wheel is a matter deserving of

great care and attention; and different authors have arrived at very opposite conclusions respecting it. The most accurate seems to be that an overshot-wheel does the more work as it moves slower: the popular reasoning adduced to prove this has been of the following kind. Suppose that a certain wheel has 30 buckets, and that 6 cubic feet of water are delivered in a second on the top of the wheel, and discharged without any loss by the way, at a certain height from the bottom of the wheel. Let this be the case whatever is the rate of the wheel's motion, the buckets being of a sufficient capacity to hold all the water which falls into them. Suppose this wheel employed to raise a weight of any kind, water, for instance, in a chain of 30 buckets, to the same altitude and with the same velocity. Suppose, farther, that when the load on the rising side of the machine is one half of that on the wheel, the wheel makes 4 revolutions in a minute, or one turn in 15 seconds. During this time, 90 cubic feet of water will have flowed into the 30 buckets, and each have received 3 cubic feet. In that case, each of the rising buckets contains $1\frac{1}{2}$ feet; and 45 cubic feet are delivered into the upper cistern, during one turn of the wheel, and 180 cubic feet in one minute.

Now, suppose the machine so loaded, by making the rising buckets more capacious, that it makes only 2 turns in a minute, or 1 turn in 30 seconds. Then each descending bucket must contain 6 cubic feet of water. If each bucket of the rising side contained 3 cubic feet, the motion of the machine would be the same as before. This is a point none will controvert. When two pounds are suspended to one end of a string which passes over a pulley, and one pound to the other end, the velocity of descent of the two pounds will be the same with that of a four pound weight, which is employed in the same manner to draw up two pounds. Our machine would therefore continue to make four turns in a minute, and would deliver 90 cubic feet during each turn, and 360 in a minute. But, by supposition, it is making only two turns in a minute; which *must* proceed from a greater load than 3 cubic feet of rising water in each rising bucket. The machine must therefore be raising *more* than 90 feet of water during one turn of the wheel, and *more* than 180 in a minute.

Thus it appears, that if the machine is turning twice as slow as before, there *is more than twice the former quantity* in the rising buckets; and more will be raised in a minute by the same expenditure of power. In like manner, if the machine go three times as slow, there must be *more than three times* the former quantity in the rising buckets, and more work will be done.

But farther we may assert, that the *more* we retard the machine to a certain practical extent, by loading it with more work of a similar kind, the greater will be its performance; and the truth of the assertion may be thus demonstrated: Let us call the first quantity of water in the rising bucket, Q; the water raised by four turns in a minute, will be $4 \times 30 \times Q = 120\,Q$. The quantity in this bucket, when the machine goes twice as slow, has been shown to be greater than $2\,Q$; call it $2\,Q + x$; the water raised by two turns in a minute will then be $2 \times 30 \times (2\,Q + x) = 120\,Q + 60\,x$. Suppose, next, the machine to go 4 times as slow, making but one turn in a minute; the rising bucket must now contain more than twice the quantity $2\,Q + x$, or more than $4Q + 2\,x$, call it $4\,Q + 2x + y$. The work done by one turn in a minute will now be $30 \times (4\,Q + 2\,x + y) = 120\,Q + 60\,x + 30\,y$. By such an induction of the work accomplished, with any rates of motion we choose, it is evident that the performance of the machine increases with every diminution of its velocity that is produced by the mere addition of a similar load of work, or that it does the more work the slower it goes. This however is abstracting from the effects of the friction upon the gudgeons of the wheel, a cause of resistance which increases with the load, though not in the same ratio.

The preceding discussion is sufficient to demonstrate, in general, the advantage of slow motion; but does not, it is confessed, point out in any degree the relation between the rate of motion and the work performed; nor even the principles on which it depends. This, however, is not necessary for the improvement of practical mechanics; but it is sufficiently manifest that there is not, in the nature of things, a maximum of performance attached to any particular rate of motion, which should, on that account, be preferred. All, therefore, we have to do, is to load the machine, and thus to diminish its speed, unless other physical circumstances throw obstacles in the way: but there are such obstacles; for in all machines there are small inequalities of action, which are unavoidable. In the action of a wheel and pinion, though made with the utmost judgment and care, there are such inequalities. These increase by the changes of form occasioned by the wearing of the machine; and much greater inequalities arise from the subsultory motions of cranks, stampers, and other parts which move unequably or reciprocally. Now, a machine may be so loaded as just to be in equilibrio with its work in the favourable position of its parts: and when this changes into one less favourable, the machine may stop, or at all events hobble, and work very irregularly: thus, the rubbing parts bear long on each other, with enormous pressures,

cut deep into one another, and greatly augment friction; so that such slow motions as these must be avoided. A little more velocity enables the machine to overcome those increased resistances by its inertia, or the great quantity of motion inherent in it; great machines possess this advantage in a superior degree, and will, consequently, work steadily with a smaller velocity.

M. de Parcieux, the inventor of the areometer described in arts. 401, &c. vol. i. was, we believe, the first who deduced, both from theory and experiment, the important result that the work done by a water-wheel was increased by diminishing its velocity. His dissertations on this subject were first inserted in *Mem. Paris. Acad. Sciences*, 1754: but lately the substance of them has appeared in various places. The student, by turning to page 472 of our first volume, will see that Mr. Smeaton arrived at the same conclusion; although the greater extent and variety of his experiments enabled him to ascertain that this general position was subject to a limitation varying with circumstances, which a judicious engineer will always carefully discriminate.

2. *Undershot-wheels.* To this class may be referred all wheels in which the motion of the water is more rapid than that of the float-boards of the wheel, so that the fluid impels them. The theory of this kind of water-wheels being so exceedingly imperfect, we can do little else than recommend to the student a cautious examination of the experiments of Smeaton. We have little to add to them here, except some results of De Parcieux and Bossut, who have shown by very good experiments that there is a sensible advantage gained by inclining the float-boards to the radius of the wheel about 20 degrees, so that each float-board when lowest shall not be vertical, but have its edge turned up the stream about 20 degrees. Such inclination causes the water to heap up along the float-board, and act by its weight: the floats should therefore be made much broader than the vane of water interrupted by them is deep.

Some engineers observing the great superiority of overshot above undershot-wheels, driven by the same expense of power, have proposed to bring the water home to the lower part of the wheel on an even bottom, and to make the float-board no deeper than the aperture of the sluice, which would permit the water to run out. The wheel they propose to be fitted with a close sole and sides, exactly fitted to the end of this trough, so that if the wheel is at rest, the water may be dammed up by the sole and float-board: it will, therefore, press forward the float-board with the whole force of the head of water. But this, however specious, cannot answer; for if we suppose no float-boards, the

water will flow out at the bottom, propelled in the manner these gentlemen suppose; and it will be supplied from behind, the water coming *slowly* from all parts of the trough to the hole below the wheel. But now add the floats, and suppose the wheel in motion with the velocity that is expected. The other floats must drag into motion all the water which lies between them, giving to the greatest part of it a motion far greater than it would have taken in consequence of the pressure of the water behind it; and the water out of the reach of the floats will remain still, which it would not have done independent of the float-boards above it, because it would have contributed to the expense of the whole. So that the motion which the wheel will acquire by this construction, must be widely different from what its projectors suppose.

As far as we are able to judge, the best way of delivering the water on an undershot-wheel in a close mill course is, to let it slide down a very smooth channel, without touching the wheel till near its bottom, where the wheel should be exactly fitted to the course; or, to make the floats much broader than the depth of the vein of water that glides down the course, and allow it to be partly intercepted by the first floats, and heap up along them, acting by its weight, after its impulse has been expended. If the bottom of the course be an arch of a circle described with a radius much greater than that of the wheel, the water which slides down will be thus gradually intercepted by the floats.

Attempts have been made to construct water-wheels which receive the impulse obliquely, like the sails of a common windmill. This would, in many situations, be a great advantage. A very slow but deep river could in this manner be made to drive our mills; and although much power is lost by the obliquity of the impulse, the remainder may be very great. Dr. Robison speaks of a wheel of this kind which was very powerful: it was a long cylindrical frame, having a plate standing out from it about a foot broad, and surrounding it with a very oblique spiral, like a corkscrew. This was immersed about $\frac{1}{4}$th of its diameter (which was nearly 12 feet), having its axis in the direction of the stream. By the work which it was performing, it seemed more powerful than a common wheel which occupied the same *breadth* of the river. Its length was not less than 20 feet: had it been twice as much, it would have nearly doubled its power without occupying more of the waterway. Perhaps such a spiral, continued quite to the axis, and moving in a hollow canal wholly filled by the stream, might be a very advantageous way of employing a deep and slow current.

In July, 1803, Mr. John Norton, of Rolls-buildings, took

out a patent for an improvement in the construction of water-mills, which is exactly this of the *spiral* wheel: how far an invention which had been publicly described seven years before in the Encyclopedia Britannica ought to be secured to Mr. Norton by a patent, we need not decide.

An undershot-wheel, with oblique float-boards, was invented by the late Mr. Besant, of Brompton; on whose widow the Society of Arts, &c. in 1801, conferred a reward of ten guineas: and, as it promises to be of great service in many situations, we have given a representation of it in pl. XXXV.

Fig. 7. A, represents the body of the water-wheel, which is hollow, in the form of a drum, and is so constructed as to resist the admission of water. B, is the axis on which the wheel turns. C, the float-boards, placed on the periphery of the wheel, each of which is firmly fixed to its rim, and to the body of the drum, in an oblique direction. D, is the reservoir that contains the water. E, the pen-stock, for regulating the quantity of water which runs to the wheel. F, represents the current that has passed such wheel.

Fig. 8. is a front view of the water-wheel, exhibiting the oblique direction in which the float-boards, C, are placed.

In the common water-wheels, more than half the quantity of that fluid passes from the gate through the wheel, without affording it any assistance: the action of the floats is resisted by the incumbent atmosphere, at the moment when these leave the surface of the tail-water; and, as a similar proportion of water with that which passed between the floats at the head, necessarily flows between them at the tail, the motion of the wheel is greatly impeded. On the contrary, by Mr. Besant's contrivance, no water can pass, excepting that which acts with all its force on the extremity of the wheel; and, as the floats emerge from the water in an oblique direction, the weight of the atmosphere is thus prevented from taking any effect. Although his new wheel is considerably heavier than those constructed on the old plan, yet it revolves more easily on its axis; the water having a tendency to float it. Lastly, repeated experiments have proved Mr. Besant's wheel to be so decidedly superior, that when working in deep tail-water, it will carry weights in the proportion of three to one; on which account it will be particularly serviceable to tide-mills. See TIDE-*mills*.

Mills with oblique floats are most useful for employing small streams, which can be delivered from a spout with a great velocity. M. Bossut has considered these with much attention, and has ascertained the best modes of construction. There are two which have nearly equal performances: 1. The vanes being placed like those of a wind-mill round the rim of a

horizontal or vertical wheel, and being made much broader than the vein of water which is to strike them perpendicularly. By these means it will be spread about on the vane in a thin sheet, and exert a pressure nearly equal to twice the weight of a column, whose base is the orifice of the spout, and whose height is the fall producing the velocity. Mills of this kind are much in use in the south of Europe. The wheel is horizontal, and the vertical axis carries the mill-stone; so that the mill is of the utmost simplicity, and this is no small recommendation. Drawings of such mills may be seen in Ramelli, Bockler, Leupold, and Belidor. See also *Bossut de Hydrodynamique*, tom. ii.

2. The vanes may be arranged round the rim of the wheel, not like the sails of a wind-mill, but in planes inclining to the radii, though parallel to the axis, or to the planes passing through the axis. They may either stand on a sole, like the oblique floats recommended by De Parcieux, as before mentioned; or they may stand on the side of the rim, not pointing to the axis, but aside from it. This disposition will admit of the spout being more conveniently disposed either for a horizontal or a vertical wheel

About the year 1746, a Mr. Williams, of Norwich, devised a water-wheel with oblique floats, of which several sets at pleasure were arranged at suitable distances upon one and the same horizontal axle. This wheel could be used advantageously where no head of water could be procured and the current ran very slowly. The description of this contrivance was given in the *Phil. Transac.* No. 478, (*New Abridgment*, Part 34.) in terms nearly as below.

The horizontal axis is cut into the form of an hexangular prism, of dimensions suitable to the force required. Into this several sets of rectangular holes are mortised, surrounding it, or arranged at equal distances when measured along the face of the prism. These holes are intended to receive different sets of sails made of iron plates, nearly 4 times as long as they are broad, all which sails are weathered in the same manner as those designed for wind-mills; only in these they are gradually curved till the extremities of their ends stand parallel to the planes of each end of the axis; viz. those ends which are farthest from the centre. This hexangular axle must, when employed, be placed parallel to the moving stream, and *may* lie even with its surface; but the engine will act most vigorously when it, and all the sails employed, are entirely under water. Each set of these sails contains six in number, being placed orderly, one in each side of the prism, and are so contrived as to be put in and taken out at pleasure. Whence it is concluded,

that when a single set of sails is made use of, the engine produces a single effect; when 2 sets, a double; and so on, till the desired momentum is acquired, with the same quantity of running water, provided there be room to fix a sufficient number of sails. It is farther to be observed, that when this engine is placed with its sails made and weathered as above directed, they will move with equal velocity, even supposing the current should change its course, and come upon them in quite a contrary direction; as happens in rivers where the tide ebbs and flows.

A model of this wheel was tried in the river at Norwich. It was fixed in a place where the water moved only 27 feet in 20 seconds, in which time the first mover made six revolutions. Its diameter was no more than 26 inches; yet it was capable of lifting 14 pounds 2 yards high, in the time just specified. The circumference of the first mover passed through a space of 42 feet in 20 seconds, so that its velocity was nearly twice that of the stream. And as the momentum will be nearly in proportion to the number of the sets of sails that are employed, its effective force is capable of being greatly augmented, while the quantity of water remains the same.

We have not been able to ascertain whether this expedient of Mr. Williams has been often tried; but we have thought it right to describe it here, as it may furnish a hint which may probably be turned to advantage by a skilful engineer, especially in the erection of tide-mills.

Floating WATER-MILLS. Although we are in this country provided with many contrivances, in which the different powers of water, steam, wind, and animal force, have been successfully applied to the purpose of grinding corn into flour, yet we have not, till very lately, met with *floating water-mills* to be worked by tides or currents; and which are moreover designed to put in motion machinery adapted to any kind of manufacture.—Messrs. Polfreeman, of Long-acre, in conjunction with Messrs. Allen, Fossenden, and Gray, have purchased the patent-right of Mr. Hawkins, and have lately completed one of those mills; which, by permission of the Board of Navigation, is stationed between London and Blackfriars-bridge. Such grant was obtained with the laudable view of reducing, if possible, the price of flour in the metropolis, and furnishing a constant supply of that necessary article of subsistence.—The simplicity of this invention renders a long description superfluous; as it consists in merely applying the force of two or three water-wheels on each side of a barge, or any other vessel better calculated to contain the interior part of the machinery. Were several mills of this kind to be stationed on the Thames, or any other river where

the tide ebbs and flows, there would doubtless numerous advantages result; for they will be far less expensive than steam-engines in the original erection, besides that they would lead to a considerable annual saving in the important article of coals.

Some other remarks connected with the subject of water-mills will be found under the words FLOUR-MILLS, PENSTOCK, STREAM-MEASURERS, and TIDE-MILLS, in this volume: and chaps. 3. and 4. book iv. of our first volume. For farther information, consult *Fabre sur les Machines Hydrauliques*, *Langsdorf's Handbuch der Maschinenlehre*, zweyter band, Dr. *Brewster's* useful additions to *Ferguson's Lectures*, or some other of the treatises mentioned in the catalogue under the word MILL.

WEIGHING-ENGINES, are often constructed in order to ascertain the weight of the loads on waggons and carts passing along turnpike-roads. To prevent the roads from being too much worn, it has been found expedient to fix by an act of parliament a certain load for each breadth of wheel; and, that such loads may not be exceeded, there are weighing-machines at several of the toll-gates, by which the loads at the several waggons, &c. passing through them can be determined.

In some of these machines the contrivance is such, that the carriage whose load is to be weighed is lifted clear from the ground, by means of four strong chains and hooks attached to a large steel-yard, whose fulcrum is raised commonly by a combination of tooth and pinion-work, moved by a winch-handle: but it is far better to have the business performed by means of apparatus placed under a horizontal frame on which the carriage may be drawn.

The most compendious and economical machine of this kind that we have seen is one, first used for weighing the riders of race-horses, and afterwards applied to the more reputable service of weighing loaded carriages.

Fig. 5. pl. XXXVII. is a plan of the machine; KLMN is the plan of a rectangular box, which has a platform lid or cover, of size sufficient for placing the wheels of a cart or waggon. The box is about a foot deep, and is sunk into the ground till the platform-cover is even with the surface. In the middle of the box is an iron lever supported on the fulcrum pin *ik*, formed like the nail of a balance, which rests with its edge on arches of hardened steel firmly fastened to the bottom of the box. This lever goes through one side of the box, and is furnished at its extremity with a hard steel pin *lm*, also formed to an edge below. In the very middle of the box it is crossed by a third nail of hardened steel *gh*, also formed to an edge, but on the

upper side. These three edges are in one horizontal plane, as in a well-made balance.

In the four corners A, A′, E′, E, of the box are firmly fixed four blocks of tempered steel, having their upper surfaces formed into spherical cavities, well polished and hard tempered. ABCDE represents the upper edge of an iron bar of considerable strength, which rests on the cavities of the steel-blocks in A and E, by means of two hard steel studs projecting from its under edge, and formed into obtuse-angled points or cones. These points are in a straight line parallel to the side KN of the box. The middle part C of this crooked bar is faced with hard-tempered steel below, and is there formed into an edge parallel to AE and KN, by which it rests on the upper edge of the steel pin *gh*, which is in the lever. In a line parallel to AE, and on the upper side of the crooked bar ACE, are fixed two studs or points of hardened steel, B and D, projecting upwards above half an inch. The platform-cover has four short feet like a stool, terminated by hard steel studs, which are shaped into spherical cavities and well polished. With these it rests on the four steel points B, B′, D′, D. The bar ACE is kneed in such a manner vertically, that the points A, B, D, E, and the edge C, are all in a horizontal plane. These particulars will be better understood by looking at the elevation in fig. 6. What has been said of the bar ACE must be understood as also said of the bar A′C′E′.

Draw through the centre of the box the line *abc* perpendicular to the line AE, BD. It is evident that the bar ACE is equivalent to a lever *abc*, having the fulcrum or axis AE resting with its extremity C on the pin *hg*, and loaded at *b*. It is also evident that *ac* is to *ab* as the load on this lever to the pressure which it exerts on the pin *gh*, and that the same proportion subsists between the whole load on the platform, and the pressure which it exerts on the pin *gh*. It will also appear, on an attentive consideration, that this proportion is no wise deranged, in whatever manner the load is placed on the platform. If very unequably, the two ends of the pin *gh* may be unequally pressed, and the lever wrenched and strained a little; but the total pressure is not changed.

If there be now placed a balance or steel-yard at the side LK, in such a manner that one end of it may be directly above the pin *lm* in the end of the lever EOF, they may be connected by a wire or slender rod, and a weight on the other arm of the balance or steel-yard may be put in equilibrio with any load that can be laid on the platform. A small counterpoise being first hung on to balance the apparatus when unloaded, any additional weight will measure the load really laid on the platform. If *ab*

be to ac as 1 to 8, and EO to EF also as 1 to 8, and if a common balance be used above, 64 pounds on the platform will be balanced by one pound in the scale, and every pound will be balanced by one-fourth of an ounce. This would be a very convenient partition for most purposes, as it would enable us to use a common balance and common weights to complete the machine: or it may be made with a balance of unequal arms, or with a steel-yard.

Some have thought to improve this instrument by using edges like those of the nails of a balance instead of points; but unless made with uncommon accuracy, they will render the balance very dull. The small deviation of the two edges A and E, or of B and D, from perfect parallelism to KN, is equivalent to a broad surface equal to the whole deviation. We imagine that, with no extraordinary care, the machine may be made to weigh within $\frac{1}{2000}$th of the truth, which is exact enough for any purpose in commerce.

It is necessary that the points be attached to the bars. Some have put the points at A and E in the blocks of steel fastened to the bottom, because the cavity there lodged water or dirt, which soon destroyed the instrument with rust. But this occasions a change of proportion in the first lever by any shifting of the crooked bars: and this will frequently happen when the wheels of a loaded cart are pushed on the platform. The cavity in the steel stud should have a little rim round it, and it should be kept full of oil. In a nice machine a quarter of an inch of quicksilver would effectually prevent all these inconveniences.

The simplest and most economical form of this machine is to have no balance or second steel-yard; but to make the first steel-yard EOF a lever of the first kind, viz. having the fulcrum between O and F, and allow it to project far beyond the box. The long or outward arm of this lever is then divided into a scale of weights, commencing at the side of the box. A counterpoise must be chosen, such as will, when at the beginning of the scale, balance the smallest load that will probably be examined. It will be convenient to carry on this scale by means of eke-weights hung on at the *extremity* of the lever, and to use but one movable weight. By this method the divisions of the scale will have always one value. The best arrangement is as follows: place the mark 0 at the beginning of the scale, and let it extend only to 100, if for pounds; or to 112, if for cwts.; or to 10 if for stones; and let the eke-weights be numbered 1, 2, 3, &c. Let the lowest weight be marked on the beam. This is always to be added to the weight shown by the operation. Let the eke-weights stand at the end of the beam, and

let the general counterpoise always hang at 0. When the cart is put on the platform, the end of the beam tilts up. Hang on the heaviest eke-weight that is not sufficient to press it down. Now complete the balance by sliding out the counterpoise. Suppose the constant load to be 312 lbs., that the counterpoise stands at 86, and that the eke-weight is 9; we have the load $= 986 + 312 = 1298$ lbs.

WEIGHING-*apparatus for goods.* Account of a new patent weighing-apparatus, invented by Mr. Hardie, of the Bengal warehouse.

Although the operation of weighing goods for sale or payment of duty requires to be conducted in the way best calculated to avoid mistakes, yet we find that the several modes now in use are subject to frequent error, through the complicated process of reckoning the totals of hundreds, quarters, and pounds respectively, and retaining them in memory until called to the book-keepers; generally amidst the bustle of porters, carmen, cranemen, and others, at a time when the laborious exertions of lifting the heavy weights on and off the board render the weighers incapable of the close attention which an accurate performance of the operation demands.

Experience shows, that in cases of mensuration the use of a scale greatly contributes both to accuracy and despatch. Mr. Hardie, therefore, by means of giving the weights a certain form, has converted the operation of weighing into an operation of mensuration, for the purpose of obtaining the important advantages of a scale, in the following manner, viz.

Fig. 1. pl. XXXII. Plan of a board for the weights, about 38 inches by 32 inches, capable of weighing a ton, on which are delineated two scales, one of larger divisions for the half-hundred weights, and the other of smaller divisions for the pound weights.

Fig. 2. Plan of a half-hundred weight of cast-iron. A an excavation forming the handle without projecting.

Fig. 3. Elevation of a half-hundred weight. A an excavation forming the handle, with B a hole for lead to adjust it.

Fig. 4 and 5. Plans of two half-hundred weights, showing the manner they are placed to fill a square allotted for the amount of one hundred weight.

Fig. 6. End elevation of the pound weights of brass fitted to the scale of one inch to a pound, the part scooped out at the sides being to receive the points of the fingers and thumb to lift them without handles.

The larger weights are placed on their particular scale beginning at A on the left, and proceeding to the right, and so

on with each row. The first hundred weight covers the blank square; the second, the square marked 1; the third, that marked 2; and and so on, respectively.

The pound weights are placed on their particular scale, beginning at B on the left, and proceeding to the right.

There is no scale for the quarter weights, being at most only two in number, namely, a half hundred weight and a quarter-hundred weight, of which the total is evident by mere inspection, and which may be of any convenient shape, and placed conspicuously above the two weights which complete the hundreds. The totals of the hundreds and pounds are indicated by the numbers next to the weights respectively on the right hand. Hence it follows that the amounts of the weights on the boards in hundreds, quarters, and pounds, are accurately known to the weighers by mere inspection; and that the book-keeper has it in his power, with a glance, to discover whether the weighers call the proper weight; which is impracticable by the present modes of weighing. Boards for weighing smaller quantities than a ton might be made on the same principle, for weights of the same dimensions, with scales adapted to the size of the board. It is to be understood that the weighing is performed without "striking the weights," which is the common phrase for lifting all the weights off the board each operation: therefore an appropriate mode, according to situation and circumstances, must be adopted to support the board with the weights, while the package weighed is removing from its board to give place to another; when, in some instances, the largeness of the package bulges out the ropes o. the board, rendering it necessary to raise the board with the weights a little higher. In some cases the prop, fig. 7. will answer the purpose, the pinion being moved by a winch. In other cases the lever, fig. 8. might be adopted, and in particular instances, the whole beam and scales, with the goods and weights, might be raised and lowered by the lever, fig. 9. assisted by the wheel and pinion.

The greatest individual weight, for the purpose of being portable, is a half-hundred weight. The common balance is used with this weighing apparatus, as it proves to be the best kind of balance known; being more true for very ponderous bodies than the steelyard, which is sometimes used where great accuracy is not required. When a very light package is to be weighed with a board adapted for a much greater weight, a hook and eye are to be used at each of the two cords, suspending the board for the weights at A and C, in order to shorten them and prevent the board from leaning to one side. Where a chain instead of a rope is used, one of its links will serve as an eye to the hook.

WHEELS acting upon each other are the instruments by which the transmission of mechanic force from one part of a system of machinery to another is commonly and conveniently effected. The due connexion of the moving parts is accomplished, either by the mutual action of proper formed teeth (see the article TEETH in this volume), by straps or endless bands, or by the friction of one face of a wheel against another. The latter method has, when adopted, been generally in small light works, where the pressure upon the different parts of the machinery is never considerable. Mr. Nicholson saw a drawing of a spinning-wheel for children, at a charity school, in which a large horizontal wheel with a slip of buff leather glued on its upper surface, near the outer edge, drove 12 spindles, at which the same number of children sat. The spindles had each a small roller, likewise faced with leather, and were capable, by an easy and instantaneous motion, of being thrown into contact with the large wheel at pleasure. Each child, therefore, could throw her own part of the apparatus into work, or cause it to stop, as often or as long as she pleased. The winding bobbins for yarn at the cotton-mills operate on the same simple and elegant principle, which possesses the advantage of drawing the thread with an equal velocity, whatever may be the quantity on the bobbin, and cannot break it. We are not aware that the same mode of communication has been adopted in large works, except in a saw-mill, by Mr. Taylor, of Southampton. In this the wheels act upon each other by the contact of the end grain of wood, instead of cogs: the whole makes very little noise, and wears very well: it has now been in use nearly twenty years. There is, of consequence, a contrivance to make the wheels bear firm against each other, either by wedges at the sockets, or by levers. This principle and method of transmitting mechanic power certainly deserves every attention; particularly as the customary mode by means of teeth requires much skill and care in the execution; and, after all, wants frequent repairs.

WIND-MILL, as its name imports, a mill for any purpose which receives its motion from the impulse of the wind.

The internal structure of wind-mills are, of course, much the same as those of water-mills: the difference between them lying chiefly in the exterior apparatus, the one to receive the force of the water, the other that of the wind. The external apparatus in a wind-mill consists chiefly of the sails or vanes, which are commonly four, placed in nearly a vertical position, and as they turn giving a rotatory motion to an axis inclining but a little from the horizon. The usual construction and appearance of the sails is too well known to need any minute description; though it may be expected that we shall treat a little of the method of weathering the sails, &c. Now a pretty distinct

idea of the surface of wind-mill sails may be obtained by conceiving a number of triangles standing perpendicular to the horizon, in which the angle contained between the hypothenuse and the base is constantly diminishing: the hypothenuse of each triangle will then be in the superficies of the vane, and they would form that superficies if their number were infinite.

Mr. *Richard Hall Gower*, a gentleman in the sea service of the East India Company, made some judicious experiments with a view of determining the proper angles of weather which ought to be given to the vanes of a vertical wind-mill; his general conclusion is, that each vane should be a spiral generated by the circular motion of a radius, and of a line moving at right angles to the plane of the circular motion. The construction he deduces from his inquiries is simple, being this: The length, breadth, and angle of weather at the extremity of a vane being given, to determine the angles of weather at different distances from the centre.

Let AB, fig. 9. pl. XXXV. be the length of the vane; BC its breadth: and BCD the angle of weather at the extremity of the vane, equal to 20 degrees. With the length of the vane AB, and breadth BC, construct the isosceles triangle ABC: from the point B draw BD perpendicular to CB, then BD is the proper depth of the vane.

Divide the line AB into any number of parts (five, for instance); at those divisions draw the lines 1E, 2F, 3G, and 4H, parallel to the line BC; also from the points of division 1, 2, 3, and 4, draw the lines 1I, 2K, 3L, and 4M, perpendicular to 1E, 2F, 3G, &c. all of them equal in length to BD. Join EI, FK, GL, and HM: then the angles 1EI, 2FK, 3GL, and 4HM, are the angles of weather at those divisions of the vane; and if the triangles be conceived to stand perpendicular with the plane of the paper, the angles I, K, L, M, and D, becoming the vertical angles, the hypothenuse of these triangles will, as before suggested, give a perfect idea of the weathering of the vane as it recedes from the centre. (*Phil. Mag.* No. 14.)

Some theoretical remarks on this subject are inserted in vol. i. art. 547.

As the direction of the wind is very uncertain, it becomes necessary to have some contrivance for turning the sails towards it, in order to receive its force in whatever way it may turn; and for this purpose two general methods are in use. In the one, the whole machine is sustained upon a movable arbour or axis, perpendicular to the horizon, which is supported by a strong stand or foot very firmly fixed in the earth; and thus by means of a lever the whole machine may be turned round as occasion requires. In the other method, only the roof, which is circular,

can be turned round by means of a lever and rollers, upon which the circular roof moves. This last kind of wind-mill is mostly built of stone, in the form of a round turret, having a large wooden ring on the top of it, above which the roof, which must likewise be of wood, moves upon rollers, as has been already mentioned. To effect this motion the more easily, the wooden ring which lies on the top of the building is furnished with a groove, at the bottom of which are placed a number of brass truckles at certain distances, and within the groove is placed another ring, by which the whole roof is supported. Beams are connected with the movable ring, and a rope is fastened to one of them, which at the lower extremity is fitted to a windlass or axis *in peritrochio*; and this rope being drawn through an iron hook fixed at the ground and the windlass turned round, the sails and roof will be turned round also, in order to catch the wind in any direction. Both these methods of construction have their advantages and disadvantages. The former is the least expensive, as the whole may be made of wood, and of any form that is thought proper; while the other requires a more costly building: and the roof being round, the building must also be so, while the former can be made of any form, but has the inconvenience of being liable to be carried off altogether by a very high wind. As both these methods of adjusting the windshaft require human assistance, it would be very desirable that the same effect should be produced by the action of the wind solely. This may be done by fixing a large wooden vane or weathercock at the extremity of a long horizontal arm, which lies in the same vertical plane with the windshaft. By this means when the surface of the vane and its distance from the axis of motion have sufficient magnitude, even a gentle breeze will so act upon this vane as to turn the machinery, and move the sail and windshaft to their proper position. This expedient may be adopted whether the mill has a movable roof or revolves upon a vertical shaft.

In art. 50. of the Introductory part of this volume, we have stated the principal results of the experiments and researches of Smeaton, relative to the shape, position, and magnitude of sails, when *four* is the number adopted. To these it might be proper to add here, some of the remarks which have been made by Parent, Euler, and other philosophers: but as none of them, except a few by Coulomb, appear any way comparable in point of practical utility with those of Smeaton, and as they include, besides, some very intricate investigations, we conceive they may be omitted without any serious disadvantage to the student.

We shall now, therefore, proceed to describe a wind-mill,

varying in many respects from the common construction. This mill was invented by Mr. *James Verrier*, of North Curry, in Somersetshire, who received a premium from the Society of Arts, for this useful specimen of his ingenuity. Mr. Verrier has contrived a register or regulator, by which the vanes are suffered to yield and give way to the impetus of the wind, when it is too forcible; and when it is too languid, it brings the vanes up to the wind, till its force is sufficient to give the mill a proper degree of velocity: by this contrivance, the wind is justly proportioned to the resistance or number of stones put to work, and the mill less liable to be set on fire, or destroyed by the violence of its motion. The vertical shaft of this mill is also much shorter than usual, in consequence of which the whole building (and especially the floor on which the stones are placed) is considerably stronger, and less liable to vibrate than in the common mills. The substance of the following description of Mr. Verrier's mill is given in *Bailey's Account of Machines, approved by the Society of Arts*, vol. ii. p. 47, the edit. of 1782.

This mill, which has *eight* quadrangular sails, is represented in fig. 7. pl. XXXVII. where AAA are the three principal posts, 20 feet, 7½ inches long, 22 inches broad at their lower extremities, 18 inches at their upper, and 17 inches thick. The column B is 12 feet, 10½ inches long, 19 inches in diameter at its lower extremity, and 16 inches at its upper: it is fixed in the centre of the mill, passes through the first floor E, having its upper end secured by the rails GG. EEE are the girders of the first floor, one of which only is seen, being 8 feet 3 inches long, 11 inches broad, and 9 thick: they are mortised into the principal posts AAA and the column B, and are about 8 feet 3 inches above the ground floor. DDD are three posts, 6 feet 4½ inches long, 9 inches broad, and 6 inches thick: they are mortised into the girders EF of the first and second floor, 2 feet 4 inches distant from the posts A, &c. FFF are the girders of the second floor, 6 feet long, 11 inches broad, and 9 thick: they are mortised into the posts A, &c. and the rest upon the upper ends of the posts D, &c. The three rails GGG are 3 feet 1½ inches long, 7 inches broad, and 3 thick: they are mortised into the posts D and the upper end of the column B, 4 feet 3 inches above the floor to their upper edges. P is one of the arms which support the extremities of the bray-trees: its length is 2 feet 4 inches, its breadth 8 inches, and its thickness 6 inches. I is one of the bray-trees into which the extremity of one of the bridge-trees K is mortised. Each bray-tree is 4 feet 9 inches long, 9½ inches broad, and 7 thick; and each bridge-tree is 4 feet 6 inches long, 9 inches broad, and 7 thick, being curved 9

inches from a right line, and furnished with a piece of brass on its upper surface to receive the under pivot of the millstones. LL are two iron screw bolts which raise or depress the fore ends of the bray-trees. MMM are three millstones, and NNN the iron spindles, each 9 feet long, on which the upper millstones are fixed. O is one of three wallowers which are fixed on the upper ends of the spindles NNN: they are 16 inches in diameter, and each is furnished with 14 trundles. *f* is one of the carriage rails in which the upper pivot of the spindle turns, and is 4 feet 2 inches long, 7 inches broad, and 4 thick. It turns on an iron bolt at one end, the other end sliding in a bracket fixed to one of the joists, and forms a mortise in which a wedge is driven to set the rail and wallower in or out of its work: *t* is the horizontal spur-wheel that gives motion to the wallowers; it is 5 feet 6 inches diameter, is fixed to the perpendicular shaft T, and has 42 cogs or teeth. The perpendicular shaft T is 9 feet 1 inch long, and 14 inches in diameter, having two iron spindles: the under spindle turns in a brass block let flush into the higher end of the column B; and the upper spindle turns in a brass plate inserted into the lower surface of the carriage rail C. The spur-wheel *r* is fixed on the upper end of the vertical shaft T, and is turned by the crown wheel *v* on the windshaft *c*; it is 3 feet two inches in diameter, and is furnished with 15 cogs. The carriage-rail C, which is fixed on the sliding kerb Z, and supports the upper pivot of the vertical shaft, is 17 feet 2 inches long, 1 foot broad, and 9 inches thick. YYQ is the fixed kerb, 17 feet 3 inches diameter, 14 inches broad and 10 thick; being mortised into the posts AAA, and fastened with screw bolts. The sliding kerb Z is of the same diameter and breadth as the fixed kerb, but its thickness is only $7\frac{1}{2}$ inches. It revolves on 12 friction rollers inserted on the upper surface of the kerb YYQ, and has 4 iron half staples Y Y, &c. fastened on its outer edge, the perpendicular arms of which are 10 inches long, 2 inches broad, and 1 inch thick, and embrace the outer edge of the fixed kerb to prevent the sliding one from being blown off. The capsills X, V, of the mill are 18 feet 9 inches long, 14 inches broad, and 1 foot thick: they are fixed at each end with strong iron screw bolts to the sliding kerb, and to the carriage-rail C. On the right hand of *w* is seen the extremity of a cross-rail, which is fixed into the capsills X and V by strong iron bolts: *e* is a bracket 5 feet long, 16 inches in its extreme breadth, and 10 inches thick; it is bushed with a strong brass collar, in which the under spindle of the windshaft turns, and is fixed to the cross rail *w*, with iron screw bolts and nuts: *b* is another bracket 7 feet long, 4 feet broad, and 10 inches thick; it is let into the fore ends of the capsills, and that it may embrace the

collar of the windshaft, it is divided into two parts which are fixed together with screw bolts. The windshaft *c* is 15 feet long, 2 feet in diameter at the fore end, and 18 inches at the back end: its pivot at the back end is 6 inches diameter; and the shaft has a hole bored through it to admit an iron rod to pass easily through. The vertical crown wheel *v* is 6 feet in diameter, having 54 cogs which turn the spur-wheel *r*. The bolster *d*, which is 6 feet 3 inches long, 13 inches broad, and 6 thick, is tenoned into the cross rail *w*, directly under the centre of the windshaft, having a brass pulley fixed in a mortise at its fore end. On the upper surface of this bolster is a groove in which the sliding bolt R moves, having a brass stud at its fore end. This sliding bolt is not distinctly seen in the figure, but the round top of the brass stud is visible below the letter *h*: the back end of the iron rod that passes through the windshaft bears against this brass stud. The sliding bolt is 4 feet 9 inches long, 9 inches broad, and 4 inches thick. At its fore end is fixed a line which passes over the brass pulley in the bolster, and appears at *a* with a weight attached to its other end, sufficient to make the sails face the wind that is strong enough to work the number of stones employed; and when the pressure of the wind is more than sufficient, the sails turn on an edge, and press back the sliding bolt, which prevents their going with too great velocity; and whenever the wind abates, the sails by the weight *a* are pressed up to their proper place again. By this apparatus the wind is regulated and justly proportioned to the resistance or work at any time to be performed; a uniformity of motion is likewise secured, and the mill is far less likely ever to move with so rapid a motion as to risque its destruction.

That the reader may understand how these effects are produced, we have represented, in fig. 8., the iron rod and the arms which bear against the vanes, or sails; *ah* is the iron rod which passes through the windshaft *c* in fig. 7.; *h* is the extremity which moves in the brass stud that is fixed upon the sliding bolt; *ai*, *ai*, &c. are the cross arms at right angles to *ah*, whose extremities *i*, *i*, similarly marked in fig. 7. bear upon the edges of the vanes. The arms *ai* are $6\frac{1}{2}$ feet long, reckoning from the centre *a*, 1 foot broad at the centre, and 5 inches thick; the eight arms *n*, *n*, &c. that carry the sails, are $18\frac{1}{2}$ feet long, their greatest breadth is 1 foot, and their thickness 9 inches, gradually diminishing to their outer ends, where they are only 3 inches in diameter: the inner ends of these arms are mortised into the windshaft. The 4 cardinal sails *m*, *m*, *m*, *m*, are each 13 feet long, 8 feet broad at their outer ends, and 3 feet at their lower extremities; *p*, *p*, &c. are the four assistant sails which have the same dimensions as the cardinal ones to which they

are joined by the line ssss. The angle of the sail's inclination when first opposed to the wind is 45 degrees, and regularly the same from end to end.

It is evident from the preceding description of this machine, that the windshaft *c* moves along with the sails: the vertical crown-wheel *v* drives the spur-wheel *r*, fixed upon the axis T, which carries also the spur-wheel *t*. This wheel impels the three wallowers O, one of which only is seen in the figure; these being fixed upon the spindles N, &c. communicate motion to the turning mill-stones.

Mr. *John Bywater*, of Nottingham, took out a patent in September, 1804, for a method of clothing and unclothing the sails of windmills *while in motion* (provided they are made after the Dutch manner), by which the mill may be clothed either in whole or in part, in an easy and expeditious manner, by a few revolutions of the sails, whether they are going fast or slow, leaving the surface smooth, even and regular in breadth from top to bottom; and in like manner the cloth, or any part of it, may be rolled or folded up to the whip at pleasure, by simple and during machinery. The invention consists in either folding or unfolding the cloths while the sails are in motion, by means of cylinders, or rollers of any shape, as long as the sails, with a toothed wheel at one end of each, working either directly or indirectly into two wheels without arms, which are hung so as to turn upon a ring of iron fixed to the shaft-head close behind the back stocks, and which may be alternately stopped; so that the wheels at the ends of the cylinders must directly, or by means of a connexion of wheels called carriers or nuts, work into them by revolving round them through the power of the wind acting on the sails; so that the cylinders must necessarily turn round, and roll up or fold, or unrol or unfold the cloth which is fastened to them, according to the respective wheel without arms which is stopped for that purpose. Such is the general contrivance: a detailed account, with figures, may be seen in the Repertory of Arts, &c. vol. vi. N. S.

Horizontal Wind-mills. Although we do not class ourselves among the advocates for horizontal wind-mills, being aware that the force of the best of them is not, at the most favourable estimate, much more than one fourth of the force of a vertical mill having equal vanes; yet, since there are some few situations and circumstances, in which the former can be adopted, where the latter would be useless, we may devote a little space to the description of one or two.

Mr. Robert Beatson took out a patent in October 1797, for a method of constructing horizontal mills, to be impelled either by wind or water. This gentleman's exclusive principle consists

in a peculiar method of constructing and disposing those surfaces upon which wind, water, &c. shall act, in which by opposing alternately a resisting and a non-resisting surface, their whole force or impulse acts in a direct manner upon the resisting side of a wheel, vane, &c. or other surface, in proportion to its extent; and when the moving force acts upon the other or returning side, the parts of the vane give way, and allow a passage with little resistance, except what is occasioned by the thin edges of the constituent flaps, together with that small portion which consists of the force requisite to the raising up or opening of these flaps.

Thus fig. 9. pl. XXXVII. is a direct view or elevation of two opposite sides of an horizontal wind-mill, wherein AP and ED are two of the upper arms, and BI and FG two of the lower arms, of which there are generally four in number, crossing each other at right angles, that is to say, four upper arms and four lower arms. CK is the vertical shaft into which the arms are fixed. There are two rectangular frames, which may either be immoveably fixed between the upper and lower arms, or they may be made to slide backwards or forwards so as to be placed near to, or farther from, the vertical shaft, as shall be required. The surface or space contained within these frames (which Mr. Beatson calls the vanes) is filled up, or covered, with any sort of thin light substance for the wind to act upon, as canvas, linen, leather, or even paper or pasteboard, which, if thought requisite, may be prepared with oil, paint, varnish, or otherwise, in such a manner as to resist wet, and to enable the wind to act upon them with the more effect. Or these spaces or vanes may be covered with any other thin or light substance or substances suitable to the purpose. It will, however, be observed, that with whatever materials these vanes are covered, it must not be in one whole piece, but divided into a number of small separate parts or flaps, placed in such a manner as to over-wrap each other a little. That is to say, if the mill is intended to turn round from left to right, the lower part of the upper flap 1 of the vane enclosed between AP and BI must over-wrap the upper part of the flap 2. The lower part of 2 must over-wrap the upper part of 3, &c., so that, all the over-wraps being on the near side, the flaps will all be close shut when the wind acts upon them, and consequently the vane will receive its whole impulse the same as if it consisted of one entire piece. The flaps in the opposite van EDFG must, however, be suspended in a different manner. That is, the over-wraps must all be on the reverse or off side, by which means, while the wind shuts all the flaps on the left, or resisting side, and is acting thereupon with its full force, opens all those on

the right or non-resisting side, and passes through between them with little or no resistance except what is occasioned by their edges, which should be as thin as possible, that the resistance may be the less; and if these flaps are properly suspended and counterpoised, the resistance will be nearly as small as if there were no covering at all upon the vane EDFG.

It is therefore evident, that if there are four of these perforated vanes, crossing each other at right angles, when the wind acts upon the resisting side with all the flaps shut, and passes through the non-resisting side with all the flaps open, the former will be impelled forward, and will be succeeded by the second vane, upon which the wind will then begin to act; and thus, by the one vane succeeding the other, a constant rotation will be produced so long as there is wind sufficient to impel them forward: and it signifies not from what quarter the wind blows, as its effect will be the same upon vanes of this construction, which will always turn the same way with any wind. If the over-wraps were made on the near side of the right vane, and the off side of the left, they would turn round the opposite way, as the right side would in that case become the resisting side, and the left the non-resisting.

The flaps of the vanes should consist of thin light frames of metal, whalebone, or any other substance fit for the purpose of stretching the canvas, linen, &c. upon, and should be suspended by two small bolts, staples, or hinges, at the upper corners, upon which they should hang freely and loosely, so as to be easily opened by the wind; or, if they are made of thin wood, or light plates of metal, there will be no occasion for stretching-frames, as the bolts or hinges may be fixed to their upper corners.

The manner of stopping and regulating these mills may either be by a brake or gripe, as in the common wind-mills, or (what is perhaps better) by a contrivance for opening or shutting all the flaps of the vanes at pleasure. This may be done by small ropes or chains, fixed to about the middle of the lower edges of the flaps, and conducted over rollers or pulleys at the top of the vanes to the inner side of the mill; by means of which ropes, or chains, all the flaps in the vanes may be at once drawn up when required. Other methods are given by Mr. Beatson. But these mills might be easily made to regulate themselves, according to the power of the wind, by means of bulky weights, or pendulums fixed to inflexible rods, and suspended out of the mill upon the arms or frames, or within it, in such a manner as to operate upon the sheaves or pinions, or the ropes that open the flaps; which, if these balls or weights are properly

situated and constructed, they will do more or less, according to the velocity at which the vanes are moving.

Mr. Beatson's principle may likewise be applied to horizontal *water-mills* in proper situations; especially for wheels to go under-water, in the current of a river, or by the ebbing and flowing of the tide, where the situation will not admit of any fall for under-shot or over-shot wheels, or when the river is apt sometimes to rise, and sometimes to fall, so much that such wheels cannot be used advantageously.

At the same time, where mills of some sort would be of great utility in raising water to supply towns, country seats, &c. or for other purposes, a wheel, on the principle here mentioned, might be used in such places to great advantage, as it would go either wholly under water, or partly so, and would always turn round the same way, whether the current was running down the river or up, as when affected by the tides, and therefore might be applied to tide-mills.

The flaps for water-wheels of this sort may be made either of thin deal or other boards, or of thin plates of metal. These water-wheels may be stopped or regulated by a sluice on either side, to stop the current, or to admit only so much as is thought necessary; and there may be other sluices to open at a suitable distance on both sides of the wheel, when the wheel sluices are shut.

Mr. Beatson proposes, likewise, to apply the same method of construction to several other objects and purposes, as to the pistons of pumps, oars, and sails for ships, ventilators, sluices, buckets for wells, &c. for a more particular description of which we must refer the reader to vol. ii. of the Repertory of Arts and Manufactures, second series, where Mr. Beatson's specification is published.

Another horizontal mill has been recently proposed by Mr. *John Jackson*; the following description of which has appeared in No. 4 of the *Retrospect of Philosophical and Mechanical Discoveries*, a very respectable and useful publication.

In this mill a stout vertical shaft carries two pairs of horizontal arms, crossing each other at right angles, so as to form suitable supports for the axles of four wheels carrying as many vanes, each placed at an equal distance from the vertical shaft, and at quadrantal distances from one to another. There are 9 toothed wheels arranged in the same horizontal plane, and mutually driving one another. The central wheel drives four others, which are called mean wheels; and these again, four others called extreme wheels: the mean and extreme wheels are attached to the arms of their axles, and are carried about with them when

in motion; the extreme wheels are fixed to their axles, and the vanes are fixed to those axles, and consequently turn with them. These vanes are posited with respect to each other, in such manner that their planes make angles of 45°, 90°, 135°, and 180°, with some variable plane; so that while one vane is completely exposed to the wind, a second and fourth are opposed to it obliquely, and the third turns its end towards it, so as to offer but little resistance. Each of the extreme wheels has twice as many teeth as the central wheel; of consequence, during one revolution of the central wheel, each extreme wheel turns half round, and each vane presents its sides alternately to the wind. The centre wheel consists of a drum or hollow shaft, through which the axle of the wheel passes. A handle is fixed to the lower extremity of the drum-shaft, by which the centre wheel is occasionally moved: this arm serves also as an index, and communicates with a circle, representing the horizon, on which are delineated the points of the compass. When the machine is in motion, the index is set and fastened to that point from which the wind blows, in order to adjust the position of the vanes with respect to the wind. Any motion of the index to the right or left of this point will alter the position of the vanes, and occasion a diminution of power in the machine; and it is by this index that the machine is stopped, or made to turn in a contrary direction; a peculiarity, when referred to wind-mills, which exclusively belongs to this contrivance.

An ingenious horizontal mill by Messrs. *Claude Françoise*, and *Jean Claude du Bost*, is described in Recueil des Machines et Inventions approuvées par l'Acad. Roy. des Sciences, tom. vii. Some judicious remarks on the comparative advantages of Horizontal and Vertical Wind-mills, and indeed much useful information on the subject of Wind-mills in general, may be found in the second vol. of Dr. *Brewster's* edition of *Ferguson's Lectures*.

For M. Prony's expedient for equalizing the velocity and effects of wind-mills, see the article CONDENSER *of Forces* in this volume.

WIPERS, in some kinds of machinery, as oil-mills, powder-mills, fulling-mills, are pieces projecting generally from horizontal axles, for the purpose of raising stampers, pounders, or heavy pistons, in vertical directions, and then leaving them to fall by their own weight.

When the wipers are only small cylinders projecting perpendicularly from the surface of the horizontal arbor, on which they are fixed, the force with which they elevate the respective stampers will not act uniformly during the whole time in which they are rising; yet, a uniformity of force and velocity is ge-

nerally a desirable thing to be attained; and may always be effected by assigning a proper form to the wipers and communicating parts. A few directions for the determination of the due shape are here given, for the use of the mechanic.

Suppose that in fig. 15. pl. XXXII. the circle described about the centre *a* is a vertical section of the arbor on which the wipers are placed; and that the line *ba* shows the distance of an arm of one of the stampers from the centre *a*: describe with centre *a* and radius *ab* an arc *bcd* . . . *k*, on which set off the equal parts *bc*, *cd*, *de*, *ef*, &c. as small as can conveniently be done: draw the radii *ac*, *ad*, *ae*, &c. on the extremities of which erect perpendiculars equal to the respective arcs *cb*, *db*, *eb*, &c. and continue them until the last of them N*k* is equal to the height to which the stamper is to be elevated: this being done, draw the curve N*b* through the extremities of the several perpendiculars to the radii, it will form an involute of the circular arc *bk* (which indeed may be either constructed thus or in the usual way at once, with a thread), and will be the figure that may be given to the upper surface of a wiper, when it is to give a uniform motion to the rising stamper. For as all the radii of curvature of N*b* are tangents to the circumference of the generating circle *bk*, the arm M*b* of the stamper can never touch the wiper in more than one point (or horizontal line, whose section is a point). When it is the point *δ*, for example, the radius *ad* which answers to the tangent *δd* will be horizontal; of consequence *δd* will be perpendicular to the horizon, and its extremity *δ* alone will touch M*b*; *δd* at the same time will be the height to which the stamper will be raised. As the same thing will obtain at all the points where the arm M*b* touches the wiper, the arm of the lever which communicates the force will be constantly the same, that is, it will be equal to *ab*; and the arm of the lever at which the resistance acts being always equal to M*b*, it follows that the stampers will be raised entirely with a uniform force, and in a direction perpendicular to the horison.

To determine the position of the point *k*, or the magnitude of the arc *kb*, the distance *ab* must be known, and the circumference C of the circle found corresponding to this radius: then make the line L equal to the height to which the stamper is to be raised: and say as C to L, so is 360^0 to the degrees and parts in the arc *bk* or the angle *bak*: draw from *a* the line *bk*, making with *ba* the angle thus found, and *k* is then ascertained. Divide the line L and the arc *bk* into an *evenly even* number of parts, set off from the points *c*, *d*, *e*, &c. of the arc the tangents in arithmetical progression, and equal to the repective parts on the line L measured from one of its extremities; and thus the

curve Nδb will be traced with great facility. The shape of the wipers as they are fixed singly in the arbor will also appear from the same figure.

In the figure we have represented only one stamper and one wiper: but it often happens that 6, 8, 10, or more stampers are worked by wipers projecting from one horizontal arbor: in this case the wipers should be so distributed that the resistance arising from all the stampers shall be as nearly as possible a constant quantity: to effect this, let all the stampers be placed at equal distances in a line parallel to the axle or arbor; let also a single spiral run once completely round from one end of the arbor to the other, and let the wipers be at equidistant positions on this spiral: thus will all the stampers be raised and permitted to fall at equidistant intervals during every rotation of the arbor.

Sometimes a small roller is fixed to the extremity of the arm Mb, to diminish the friction; and in this case a curve must be drawn with Nb, parallel to it, and at a distance equal to the radius of the roller; this new curve exhibiting the shape and position of the upper face of the wiper.

In some machines stampers or pistons are raised by giving a proper curvature to the arm Mb, and fixing the roller upon the extremity of a bent bar, whose end is in the direction of a radius produced: in this case the arm must be shaped into part of a cycloid, the radius of whose generating circle is equal to the distance from the extremity of the wiper to the centre of the arbor; and this curve must be placed at the outer part of the rollers, to form the lower face of the arm.

The wiper may often be formed with great propriety like the Archimedean spiral, according to the method described by Dr. Brewster, and thus raise a stamper with a uniform motion. To this end let AH (fig. 12. pl. XXXII.) be a wheel put into motion by any power which is sufficient to raise the weight MN, by its extremity O, from O to e, in the same time that the wheel moves round one fourth of its circumference, it is required to fix upon its rim a wing OBCDEH which shall produce this effect with a uniform effort. Divide the quadrant OH into any number of equal parts Om, mn, &c. the more the better, and oe into the same number ob, bc, cd, &c. and through the points m, n, p, H, draw the indefinite lines AB, AC, AD, AE, and make AB equal to Ab, AC to Ac, AD to Ad, and AE to Ae; then through the points O, B, C, D, E, draw the curve OBCDE, which is a portion of the spiral of Archimedes, and will be the proper form for the wiper or wing OHE. It is evident that when the point m has arrived at O, the extremity of the frame will have arrived at b, because AB is equal to Ab; and for the

same reason, when the points n, p, H, have successively arrived at O, the extremity of the frame will have arrived at the corresponding points c, d, e. The motion therefore will be uniform, because the space described by the weight is proportional to the space described by the moving power, ob being to oc, as om to on. If it be required to raise the weight MN with an accelerated or retarded motion, we have only to divide the line oe, according to the law of acceleration or retardation, and divide the curve OBCDE as before. It is scarcely necessary to add, that the vertical bar between N and M must be kept from lateral deviations, by being made either to run between rollers, or to slide in a groove.

We have all along supposed that the wheel or the arbor which carries the wipers turns upon a horizontal axis: we might exhibit methods by which stampers, &c. could be raised uniformly by wheels moving at right angles to the plane in which these stampers move; but such methods are intricate and not much to be recommended, as they may always be avoided by a small addition of the machinery, or some slight modifications in its general distribution.

WORCESTER, Marquis of, his *Century of Inventions*. The curious and interesting tract, first published under this title about the middle of the seventeenth century, though often referred to by mechanical writers, being but little known, and containing various striking hints, some now matured, and others not yet completed; it is conceived its entire insertion in this place will be acceptable to the inquisitive reader.

1. Several sorts of seals, some showing by screws, others by gages, fastening or unfastening all the marks at once: others by additional points and imaginary places, proportionable to ordinary escutcheons and seals at arms, each way palpably and punctually setting down (yet private from all others but the owner, and by his assent), the day of the month, the day of the week, the month of the year, the year of our Lord, the names of the witnesses, and the individual place where any thing was sealed, though in ten thousand several places, together with the very number of lines contained in a contract, whereby falsification may be discovered, and manifestly proved, being upon good grounds suspected.

Upon any of these seals a man may keep accounts of receipts and disbursements from one farthing to a hundred millions, punctually showing each pound, shilling, penny, or farthing.

By these seals likewise any letter, though written but in English, may be read and understood in eight several languages, and in English itself to clean contrary and different sense, un-

known to any but the correspondent, and not to be read or understood by him neither, if opened before it arrive unto him; so that neither threats, nor hopes of reward, can make him reveal the secret, the letter having been intercepted, and first opened by the enemy.

2. How ten thousand persons may use these seals to all and every of the processes aforesaid, and yet keep their secrets from any but whom they please.

3. A cipher and character so contrived, that one line, without returns and circumflexes, stand for each and every of the twenty-four letters; and as ready to be made for the one letter as the other.

4. This invention refined, and so abbreviated, that a point only showeth distinctly and significantly any of the twenty-four letters; and these very points to be made with two pens, so that no time will be lost, but as one riseth, the other may make the following letter, never clogging the memory with several figures for words, and combination of letters; which with ease, and void of confusion, are thus speedily and punctually, letter for letter, set down by naked and not multiplied points. And nothing can be less than a point, the mathematical definition of being *Cujus pars nulla*. And of a motion no swifter imaginable than *Semiquavers* or *Releshes*, yet applicable to this manner of writing.

5. A way, by a circular motion, either along a rule or ringwise, to vary any alphabet, even this of points, so that the self-same point individually placed, without the least additional mark of variation of place, shall stand for all the twenty-four letters, and not for the same letter twice in ten sheets writing; yet as easily and certainly read and known, as if it stood but for one and the self-same letter constantly signified.

6. How at a window, as far as eye can discover black from white, a man may hold discourse with his correspondent, without noise made or notice taken; being, according to occasion given, and means afforded, *Ex re natâ*, and no need of provision before-hand; though much better if foreseen, and means prepared for it, and a premeditated course taken by mutual consent of parties.

7. A way to do it by night as well as day, though as dark as pitch is black.

8. A way how to level and shoot cannon by night as well as by day, and as directly; without a platform or measures taken by day, yet by plain and infallible rule.

9. An engine, portable in one's pocket, which may be carried and fastened on the inside of the greatest ship, *Tanquam aliud*

agens, and at any appointed minute, though a week after, either of a day or night, it shall irrecoverably sink that ship.

10. A way from a mile off to drive and fasten a like engine to any ship, so as it may punctually work the same effect, either for time or execution.

11. How to prevent and safeguard any ship from such an attempt by day or night.

12. A way to make a ship not possible to be sunk, though shot an hundred times betwixt wind and water by cannon, and should lose a whole plank, yet, in half an hour's time, should be made as fit to sail as before.

13. How to make such false decks as in a moment should kill and take prisoners as many as should board the ship, without blowing the decks up, or destroying them from being reducible, and in a quarter of an hour's time should recover their former shape, and to be made fit for any employment, without discovering the secret.

14. How to bring a force to weigh up an anchor, or to do any forcible exploit, in the narrowest or lowest room in any ship, where a few hands shall do the work of many; and many hands applicable to the same force, some standing, others sitting, and by virtue of their several helps, a great force augmented in little room, as effectually as if there were sufficient space to go about with an axletree, and work far from the centre.

15. A way how to make a boat work itself against wind and tide, yea, both without the help of man or beast; yet so that the wind or tide, though directly opposite, shall force the ship or boat against itself; and in no point of the compass, but it shall be as effectual as if the wind were in the pump, or the stream actually with the course it is to steer, according to which the oars shall row, and necessary motions work and move towards the desired port or point of the campass.

16. How to make a sea-castle or fortification cannon-proof, and capable of a thousand men, yet sailable at pleasure to defend a passage, or in an hour's time to divide itself into three ships, as fit and trimmed to sail as before: and even whilst it is a fort or castle, they shall be unanimously steered, and effectually be driven by an indifferent strong wind.

17. How to make upon the Thames a floating garden of pleasure, with trees, flowers, banqueting houses, and fountains, stews for all kinds of fishes, a reserve for snow to keep wine in, delicate bathing places, and the like; with music made with mills; and all in the midst of the stream, where it is most rapid.

18. An artificial fountain to be turned like an hour-glass, by a child, in the twinkling of an eye, it holding great quantity of

water, and of force sufficient to make snow, ice, and thunder, with a chirping and singing of birds, and showing of several shapes and effects, usual to fountains of pleasure.

19. A little engine within a coach, whereby a child may stop it, and secure all persons within it, and the coachman himself, though the horses be never so unruly in a full career: a child being sufficiently capable to loosen them, in what posture soever they should have put themselves, turning never so short; for a child can do it in the twinkling of an eye.

20. How to bring up water balance-wise, so that as little weight or force as will turn a balance will be only needful, more than the weight of the water within the buckets, which counterpoised, empty themselves one into the other, the uppermost yielding its water (how great a quantity soever it holds) at the self-same time the lowermost taketh it in, though it be an hundred fathom high.

21. How to raise water constantly with two buckets only day and night, without any other force than its own motion, using not so much as any force, wheel, or sucker, nor more pulleys than one, on which the cord or chain rolleth with a bucket fastened at each end. This, I confess, I have seen and learned of the great mathematician Claudius his studies at Rome, he having made a present thereof unto a cardinal; and I desire not to own any other man's inventions, but, if I set down any, to nominate likewise the inventor.

22. To make a river in a garden to ebb and flow constantly, though twenty foot over, with a child's force, in some private room or place out of sight, and a competent distance from it.

23. To set a clock in a castle, the water filling the trenches about it; it shall show by ebbing and flowing the hours, minutes, and seconds, and all the comprehensible motions of the heavens, and counterlibation of the earth, according to Copernicus.

24. How to increase the strength of a spring to such an height, as to shoot bumbasses and bullets of an hundred pound weight a steeple height, and a quarter of a mile off and more, stone-bow-wise, admirable for fire-works and astonishing of besieged cities, when without warning given by noise they find themselves so forcibly and dangerously surprised.

25. How to make a weight that cannot take up an hundred pound, and yet shall take up two hundred pound, and at the self-same distance from the centre; and so proportionably to millions of pounds.

26. To raise weight as well and as forcibly with the drawing back of the lever as with the thrusting it forwards: and by that

means to lose no time in motion or strength. This I saw in the Arsenal at Venice.

27. A way to remove to and fro huge weights, with a most inconsiderable strength, from place to place. For example, ten ton with ten pounds, and less; the said ten pounds not to fall lower than it makes the ten ton to advance or retreat upon a level.

28. A bridge portable in a cart with six horses, which in a few hours time may be placed over a river half a mile broad, whereon with much expedition may be transported horse, foot, and cannon.

29. A portable fortification able to contain five hundred fighting men, and yet in six hours time may be set up, and made cannon-proof, upon the side of a river or pass, with cannon mounted upon it, and as complete as a regular fortification, with half-moons and counterscarps.

30. A way in one night's time to raise a bulwark twenty or thirty foot high, cannon-proof, and cannon mounted upon it, with men to overlook, command, and batter a town: for though it contain but four pieces, they shall be able to discharge two hundred bullets each hour.

31. A way how safely and speedily to make an approach to a castle or town-wall, and over the very ditch, at noon-day.

32. How to compose an universal character methodically and easy to be written, yet intelligible in any language; so that if an Englishman write it in English, a Frenchman, Italian, Spaniard, Irish, Welsh, being scholars; yea, Grecian or Hebritian, shall as perfectly understand it in their own tongue, as if they were perfectly English, distinguishing the verbs from nouns, the numbers, tenses, and cases, as properly expressed in their own language as it was written in English.

33. To write with a needle and thread, white, or any colour upon white, or any other colour, so that one stitch shall significantly show any letter, and as readily and as easily show the one letter as the other, and fit for any language.

34. To write by a knotted silk string, so that every knot shall signify any letter with comma, full-point, or interrogation, and as legible as with pen and ink upon white paper.

35. The like by the fringe of gloves.

36. By stringing of bracelets.

37. By pinked gloves.

38. By holes in the bottom of a sieve.

39. By a lattin or plate lanthorn.

40. By the smell.

41. By the taste.

42. By the touch.

By these three senses as perfectly, distinctly, and unconfusedly, yea as readily as by the sight.

43. How to vary each of these, so that ten thousand may know them, and yet keep the understanding part from any but their correspondent.

44. To make a key of a chamber door, which to your sight hath its wards and rose pipe but paper-thick, and yet at pleasure in a minute of an hour shall become a perfect pistol, capable to shoot through a breast-plate commonly of carabine proof, with prime, powder, and firelock, undiscoverable in a stranger's hand.

45. How to light a fire and a candle at what hour of the night one waketh, without rising or putting one's hand out of the bed. And the same thing becomes a serviceable pistol at pleasure: yet by a stranger, not knowing the secret, seemeth but a dexterous tinder-box.

46. How to make an artificial bird to fly which way and as long as one pleaseth, by or against the wind, sometimes chirping, other times hovering, still tending the way it is designed for.

47. To make a ball of any metal, which, thrown into a pool or pail of water, shall presently rise from the bottom, and constantly show by the superficies of the water the hour of the day or night, never rising more out of the water than just to the minute it showeth of each quarter of the hour; and if by force kept under water, yet the time is not lost, but recovered as soon as it is permitted to rise to the superficies of the water.

48. A screwed ascent, instead of stairs, with fit landing-places to the best chambers of each story, with back stairs within the noell of it, convenient for servants to pass up and down to the inward rooms of them unseen and private.

49. A portable engine, in way of a tobacco tongs, whereby a man may get over a wall, or get up again being come down, finding the coast proving unsecure unto him.

50. A complete light portable ladder, which taken out of one's pocket may be by himself fastened an hundred foot high, to get up by from the ground.

51. A rule of gradation, which, with ease and method, reduceth all things to a private correspondence, most useful for secret intelligence.

52. How to signify words, and a perfect discourse, by jangling of bells of any parish church, or by any musical instrument within hearing, in a seeming way of tuning it, or of any unskilful beginner.

53. A way how to make hollow and cover a water screw, as big and as long as one pleaseth, in an easy and cheap way.

54. How to make a water-screw tight, and yet transparent, and free from breaking; but so clear, that one may palpably see the water, or any heavy thing, how and why it is mounted by turning.

55. A double water screw, the innermost to mount the water, and the outermost for it to descend more in number of threads, and consequently in quantity of water, though much shorter than the innermost screw, by which the water ascendeth, a most extraordinary help for the turning of the screw to make the water rise.

56. To provide and make that all the weights of the descending side of a wheel shall be perpetually farther from the centre than those of the mounting side, and yet equal in number and heft to the one side as the other. A most incredible thing, if not seen, but tried before the late king (of blessed memory) in the Tower, by my directions, two extraordinary embassadors accompanying his majesty, and the Duke of Richmond, and Duke of Hamilton, with most of the Court attending him The wheel was fourteen foot over, and forty weights of fifty pounds a piece. Sir William Balfore, then Lieutenant of the Tower, can justify it, with several others. They all saw, that no sooner these great weights passed the diameter line of the lower side, but they hung a foot farther from the centre, nor any sooner passed the diameter line of the upper side, but they hung a foot nearer. Be pleased to judge the consequence.

57. An ebbing and flowing water-work in two vessels, into either of which the water standing at a level, if a globe be cast in, instead of rising, it presently ebbeth, and so remaineth until a like globe be cast into the other vessel, which the water is no sooner sensible of, but that vessel presently ebbeth, and the other floweth, and so continueth ebbing and flowing until one or both of the globes be taken out, working some little effect besides its own motion, without the help of any man within sight, or hearing: but, if either of the globes be taken out with ever so swift or easy a motion, at the very instant the ebbing and flowing ceaseth: for, if during the ebbing you take out the globe, the water of that vessel presently returneth to flow, and never ebbeth after until the globe be returned into it, and then the motion beginneth as before.

58. How to make a pistol to discharge a dozen times with one loading, and without so much as once new priming requisite, or to change it out of one hand into the other, or stop one's horse.

59. Another way as fast and effectual, but more proper for carabines.

60. A way, with a flask appropriated unto it, which will

furnish either pistol or carabine with a dozen charges in three minutes time, to do the whole execution of a dozen shots, as soon as one pleaseth, proportionably.

61. A third way, and particular for musquets, without taking them from their rests to charge or prime, to a like execution, and as fast as the flask, the musquet containing but one charge at a time.

62. A way for a barquebuss, a crock, or ship-musquet, six upon a carriage, shooting with such expedition, as without danger one may charge, level, and discharge them sixty times in a minute of an hour, two or three together.

63. A sixth way, most excellent for sakers, differing from the other, yet as swift.

64. A seventh, tried and approved before the late king (of ever blessed memory) and an hundred lords and commons, in a cannon of eight inches half quarter, to shoot bullets of sixty-four pounds weight, and twenty-four pounds of powder, twenty times in six minutes; so clear from danger, that, after all were discharged, a pound of butter did not melt being laid upon the cannon-britch, nor the green oil discoloured that was first anointed and used between the barrel thereof, and the engine, having never in it, nor within six foot, but one charge at a time.

65. A way that one man in the cabin may govern the whole side of ship-musquets, to the number (if need require) of 2 or 3000 shots.

66. A way that against several avenues to a fort or castle, one man may charge fifty cannons playing, and stopping when he pleaseth, though out of sight of the cannon.

67. A rare way likewise for musquettoons fastened to the pummel of the saddle, so that a common trooper cannot miss to charge them, with twenty or thirty bullets at a time, even in full career.

When first I gave my thoughts to make guns shoot often, I thought that there had been but one only exquisite way inventible: yet, by several trials, and much charge, I have perfectly tried all these.

68. An admirable and most forcible way to drive up water by fire, not by drawing or sucking it upwards, for that must be, as the philosopher calleth it, *Intra sphæram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessels be strong enough; for, I have taken a piece of a whole cannon, whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the broken

end, as also the touch-hole; and making a constant fire under it, within twenty-four hours it burst, and made a great crack: so that having a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other. I have seen the water run like a constant fountain stream forty foot high; one vessel of water rarefied by fire driveth up forty of cold water. And a man that tends the work is but to turn two cocks, that, one vessel of water being consumed, another begins to force and re-fill with cold water, and so successively, the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim, between the necessity of turning the said cocks.

69. A way how a little triangle screwed key, not weighing a shilling, shall be capable and strong enough to bolt and unbolt round about a great chest, an hundred bolts through fifty staples, two in each, with a direct contrary motion, and as many more from both sides and ends, and at the self-same time shall fasten it to the place, beyond a man's natural strength to take it away: and in one and the same turn, both locketh and openeth it.

70. A key with a rose-turning pipe, and two roses pierced through endwise the bit thereof, with several handsomely contrived wards, which may likewise do the same effects.

71. A key perfectly square, with a screw turning within it, and more conceited than any of the rest, and no heavier than the triangle-screwed key, and doth the same effects.

72. An escutcheon to be placed before any of these locks with these properties.

1. The owner (though a woman) may with her delicate hand vary the ways of coming to open the lock ten millions of times, beyond the knowledge of the smith that made it, or of me who invented it.
2. If a stranger open it, it setteth an alarm a-going, which the stranger cannot stop from running out; and besides, though none should be within hearing, yet it catcheth his hand, as a trap doth a fox; and though far from maiming him, yet it leaveth such a mark behind it, as will discover him if suspected; the escutcheon or lock plainly showing what money he hath taken out of the box to a farthing, and how many times opened since the owner had been in it.

73. A transmittable gallery over any ditch or breach in a town-wall, with a blind and parapet cannon-proof.

74. A door, whereof the turning of a key, with the help and motion of the handle, makes the hinges to be of either side, and to open either inward or outward, as one is to enter or to go out, or to open in half.

75. How a tape or ribbon weaver may set down a whole discourse, without knowing a letter, or interweaving any thing suspicious of other secret than a new-fashioned ribbon.

76. How to write in the dark as straight as by day or candle light.

77. How to make a man to fly; which I have tried with a little boy of ten years old in a barn, from one end to the other, on an hay-mow.

78. A watch to go constantly, and yet needs no other winding from the first setting on the cord or chain, unless it be broken, requiring no other care from one than to be now and then consulted with, concerning the hour of the day or night; and, if it be laid by a week together, it will not err much, but, the oftener looked upon, the more exact it sheweth the time of the day or night.

79. A way to lock all the boxes of a cabinet (though never so many) at one time, which were by particular keys appropriated to each lock opened severally, and independent the one of the other, as much as concerneth the opening of them, and by these means cannot be left opened unawares.

80. How to make a pistol-barrel no thicker than a shilling, and yet able to endure a musket-proof of powder and bullet.

81. A comb-conveyance carrying of letters without suspicion, the head being opened with a needle-screw, drawing a spring towards them; the comb being made but after an usual form carried in one's pocket.

82. A knife, spoon, or fork, in an usual portable case, may have the like conveyance in their handles.

83. A rasping-mill for hartshorn, whereby a child may do the work of half a dozen men, commonly taken up with that work.

84. An instrument whereby persons, ignorant in arithmetic, may perfectly observe numerations and subtractions of all sums and fractions.

85. A little ball made in the shape of plum or pear, being dexterously conveyed or forced into a body's mouth, shall presently shoot forth such and so many bolts of each side and at both ends as without the owner's key can neither be opened or filed off, being made of tempered steel, and as effectually locked as an iron chest.

86. A chair made *a-la-mode*, and yet a stranger being persuaded to sit down in it, shall have immediately his arms and thighs locked up beyond his own power to loosen them.

87. A brass mould to cast candles, in which a man may make five hundred dozen in a day, and add an ingredient to the tallow which will make it cheaper, and yet so that the candles shall look whiter and last longer.

88. How to make a brazen or stone head, in the midst of a great field or garden, so artificial and natural, that though a man speak never so softly, and even whispers into the ear thereof, it will presently open its mouth, and resolve the question in French, Latin, Welsh, Irish, or English, in good terms, uttering it out of his mouth, and then shut it until the next question be asked.

89. White silk knotted in the fingers of a pair of white gloves, and so contrived without suspicion, that playing at Primero at cards, one may, without clogging his memory, keep reckoning of all sixes, sevens, and aces, which he hath discarded.

90. A most dexterous dicing-box, with holes transparent, after the usual fashion, with a device so dexterous, that, with a knock of it against the table, the four good dice are fastened, and it looseneth four false dice made fit for his purpose.

91. An artificial horse, with saddle and caparizons fit for running at the ring, on which a man being mounted, with his lance in his hand, he can at pleasure make him start, and swiftly to run his career, using the decent posture with *bonne grace*, may take the ring as handsomely, and running as swiftly as if he rode upon a barbe.

92. A screw made like a water-screw, but the bottom made of iron-plate spadewise, which at the side of a boat emptieth the mud of a pond, or raiseth gravel.

93. An engine whereby one man may take out of the water a ship of five hundred ton, so that it may be calked, trimmed, and repaired, without need of the usual way of stocks, and as easily let it down again.

94. A little engine portable in one's pocket, which placed to any door, without any noise, but on a crack, openeth any door or gate.

95. A double cross-bow, neat, handsome, and strong, to shoot two arrows, either together, or one after the other, so immediately, that a deer cannot run two steps, but if he miss of one arrow, he may be reached with the other, whether the deer run forward, sideward, or start backward.

96. A way to make a sea-bank so firm and geometrically strong, that a stream can have no power over it; excellent likewise to save the pillar of a bridge, being far cheaper and stronger than stone walls.

97. An instrument whereby an ignorant person may take any thing in perspective, as justly, and more than the skilfullest painter can do by his eye.

98. An engine so contrived, that working the *primum mobile* forward or backward, upward or downward, circularly or

cornerwise, to and fro, straight, upright, or downright, yet the pretended operation continueth and advanceth, none of the motions above mentioned hindering, much less stopping the other; but unanimously, and with harmony agreeing, they all augment and contribute strength unto the intended work and operation: and therefore I call this a semi-omnipotent engine, and do intend that a model thereof be buried with me.

99. How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pound descending doth what nothing less than one hundred pound can effect.

100. Upon so potent a help as these two last mentioned inventions, a water-work is by many years experience and labour so advantageously by me contrived, that a child's force bringeth up an hundred foot high an incredible quantity of water, even two foot diameter, so naturally, that the work will not be heard even into the next room; and, with so great ease and geometrical symmetry, that though it work day and night from one end of the year to the other, it will not require forty shillings reparation to the whole engine, nor hinder one's day-work. And I may boldly call it *The most stupendous work in the whole world:* not only with little charge to drain all sorts of mines and furnish cities with water, though never so high seated, as well to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions; but likewise supplying the rivers with sufficient to maintain and make them portable from town to town, and for the bettering of lands all the way it runs; with many more advantageous, and yet greater effects of profit, admiration, and consequence. So that deservedly I deem this invention to crown my labours, to reward my expenses, and make my thoughts acquiesce in way of further inventions. This making up the whole century, and preventing any further trouble to the reader for the present, meaning to leave to posterity a book, wherein under each of these heads the means to put in execution, and visible trial, all and every of these inventions, with the shape and form of all things belonging to them, shall be printed by brass-plates.

In Bonum Publicum, & ad majorem DEI gloriam.

YARN, in general denotes the manufacture of wool, hemp, flax, cotton, &c. converted into filaments or threads, which are subservient to a variety of useful purposes.

Formerly, all yarn was spun or twisted by means of the distaff, or wheel; but lately, the ingenuity of mechanics, and the

powers of machinery, have been called in aid to facilitate that operation: in June, 1787, Messrs. *John Kendrew* and *Thomas Porthouse* obtained a patent for their invention of a machine, upon new principles, designed to spin yarn from hemp, tow, flax, or wool.—As this privilege is now expired, and such contrivance promises to be very useful in the woollen as well as other manufactures, we shall subjoin an account of the construction, as extracted from the specification inserted in the Repertory of Arts and Manufactures.

This machine may be worked by water, or as a horse-mill, or in any other way, and is made and used in the following manner. There is a cylinder, marked A in the drawing, fig. 1. plate XXXVII., three feet diameter, and ten inches broad, made of dry wood or metal, turned true and covered on its circumference with a smooth leather, upon which are placed the rollers marked D, covered with leather, and supported in their situations by the slits in the covered piece of wood marked K in which the iron axes of the rollers turn, but suffers them to press on the wheel marked A. There must be another piece similar to the above, to support the other end of the rollers. These rollers are of different weights. The upper roller marked DI is two stone, the rest decreasing to the last, which is only two pounds weight and one half. There is an iron fluted roller, marked F, furnished with a toothed wheel at each end, and a wood one, marked G, covered with cloth, and over it a smooth leather. There is an assisting roller, marked H, of fluted iron. These rollers are supported by their axes, turning in the slit, marked 2, of the piece of wood, marked M (fig. 3.), which is here separated from the end of the frame marked 8, to show the rollers and wheel work. The rollers marked G and F are squeezed together by means of the lever marked *p*, and its weight marked *w* (fig. 3.). The roller marked H is pressed to the mark G by its axis, acting upon the inclined plane marked *x* (fig. 3.). There is a rubbing roller covered with woollen cloth, and on its axis is a small wheel, maked I, driven by the wheel marked S. This roller rests upon the roller marked G, and by its motion prevents any dirt or fibres from adhering to it. There is a cloth, marked N, revolving over two rollers marked O, O, which has motion given to it from the wheel marked C, by means of another wheel marked P. This cloth moves at the same rate as the surface of the wheel marked A. There is a supporter, marked Y, of the axis of the wheels marked O, P, but is removed, in order to show them; it is fixed by its tenons in the mortises marked Z, Z. The roller marked B is kept in action by its endeavour to slip down the inclined plane at the top of the piece marked Y, thereby pressing against the re-

volving cylinder; and another piece, similar to this, must be understood to support the other end of the roller's axis. By the side of this revolving cloth is a table placed, of the same length and breadth as the cloth is, to which belong two smooth cloths or leathers, of the same size as the table. The machine being thus prepared, the attendant or workman must take a quantity of hemp, tow, flax, or wool, more or less, according to the fineness of the thread to be made, and lay or spread it evenly upon one of the smooth cloths on the table, then place it on the revolving cloth marked N, motion being communicated to the roller marked F by wheel-work as usual, from a water, horse, or other kind of mill, which wheel-work is communicated to the wheel marked Q, on whose axis is a nut, which turns the wheel marked C; and thereby the cylinder marked A moves, and with it all the rollers; by which motion the hemp, tow, flax, or wool, is drawn forward. The cloth turns down, but the hemp, tow, flax, or wool, go upon the cylinder marked A, under the roller marked B, and so forward under the rollers marked D, then falls in between the rollers marked G, F, turns under the roller marked G, and over the roller marked H, which, as it gives the rollers hold of the hemp, tow, flax, or wool, in two places, enables them to draw forward the long fibres thereof, though many of them are to draw from under the marks 4 or 5 of the pressing-rollers marked D; it then falls into a canister, marked R, and as by the wheel-work the rollers marked F, G, H, move three times faster than the cloth and cylinder, the sliver must be three times longer than when presented. By the time this is drawing, the other cloth is filled with hemp, tow, flax, or wool, as before, and laid upon the revolving roller, laying the hemp, tow, flax, or wool, over the end of the other, which goes forward as before, and thus a continued sliver is produced as long as the machine continues its motion. But in order that this sliver may come out of the canister marked R without entanglement, it must pass through an instrument marked 5 (fig. 3.), placed over the rollers marked F, G, its open side marked T, to the cylinder at mark 4, supported by its ends marked V, V, in the slit marked W, of the before-described pieces marked K. The aperture X is so small as to press the fibres close to each other in their passage through it previous to their passing the rollers, by which means they remain pressed side by side in the sliver, and will not entangle. These thick slivers are drawn smaller by a similar process, and in the same manner are used for cottons; but the machines for drawing are all of the same structure as the above, except that they have no revolving cloth. The sliver is applied to the cylinder under the roller marked B, which draws it forward under all the rollers, as before described,

drawing it out, or lengthening it, every fresh machine through which it presses, till it be small enough for the spinning machine. It must be remarked, that the cylinders are made less in diameter, according to the different smallness of the sliver intended to be drawn upon them at the first: whilst the sliver is at its greatest thickness, the cylinder is required to be three feet diameter, as above described, the next rather less, and so on to the last, which is only two feet. The aperture of the bottom of the contractor belonging to each machine is also made one third part smaller than another in succession, from the greatest to the smallest cylinder; as also the drawing rollers marked F, G, H, are furthest from the pressing-roller marked D in the longest cylinder, and nearest at the smaller cylinder. At the largest cylinder the distance is about nine inches, and the smallest about four inches; but their distance cannot in all cases be fixed, as it depends on the different length of the slivers of the hemp, tow, flax, or wool; long ones requiring the distances mentioned, and short ones requiring the distances much shorter than is here specified.

The following several letters or marks are in the machine figured 2. The spinning machine, as to its drawing principle, is the same as the drawing machine. The slivers are presented to it in canisters marked A, and drawn over a cylinder marked B covered with rollers marked D. The fibres which are to form the thread are drawn from the cylinder by the rollers marked C, the under roller of which is made of fluted iron, the other of wood, covered with leather; they move six or eight times faster than the cylinder marked B; are enabled to draw the hemp, tow, flax, or wool, forward from under the pressing-rollers marked D, by being squeezed together with the weights and crooks marked *a, a*, locked to the small part of the rollers marked C. There is a belt of smooth cloth, marked E, moving on two rollers, which are turned by the wheel marked F, on the axis of the fluted roller; at the opposite end of which, as at the mark G, is a nut, which turns the wheel marked H, on whose axis is another nut, turning the wheel marked I, and thereby the cylinder marked B, with all its rollers. These rollers move in curved pieces of wooden metal, marked K, which, to prevent confusion, are not represented in their places: they have slits in them, in which the rollers' axis are guided, but so deep as at all times to suffer the rollers to press upon the cylinder. These rollers are covered with cloth and leather. The top roller is about ten pounds weight, decreasing to the sixth roller, which is only about one pound weight: the yarn is turned by the spindles marked L, and rubbed over the wet cloth belt if spinning linen yarn, but if spinning worsted yarn the

belt must be removed, that it may not touch it as it passes to the spool, which it coils round as fast as the rollers let it out. The spindles marked L are turned by a bolt from the wheel marked M, which derives its motion from the mill, and by a wheel on its axis communicates it to the roller under the mark C by the wheel marked F, and so to the rest, as above described. The hemp, tow, flax, or wool, is twined in the same manner as cotton is by mills.

FINIS.

OTHER WORKS BY DR. GREGORY.

---

1. LESSONS ASTRONOMICAL AND PHILOSOPHICAL, for the Amusement and Instruction of British Youth. 12mo. 5th edition, price 5s. boards.

2. A TREATISE ON ASTRONOMY, in which the elements of the science are deduced in a natural order, from the appearances of the heavens to an observer on the earth; demonstrated on mathematical principles, and explained by an application to the various phenomena. One large vol. 8vo. price 9s. boards.

3. A *Translation* of M. Hauy's ELEMENTARY TREATISE ON NATURAL PHILOSOPHY, with many notes and illustrations. 2 vols. 8vo. price 14s. boards.

*** The two latter works, with the Mechanics, constitute together a complete System of Natural Philosophy.

4. In conjunction with Dr. *Hutton*, the third volume of A COURSE OF MATHEMATICS for the use of the Gentlemen Cadets in the Royal Military Academy, Woolwich. Price 12s.

5. In conjunction with *John Mason Good*, M.D. F.R.S. and Mr. *Newton Bosworth*, the PANTOLOGIA, a Universal Dictionary of Arts, Sciences, and Words; complete in 12 vols. 8vo. Of this work, Dr. *Gregory* was the general Editor.

6. *Letters to a Friend, on the* EVIDENCES, DOCTRINES, AND DUTIES OF THE CHRISTIAN RELIGION. 2 vols. crown 8vo. 4th edition. 14s. boards.

7. *Dissertations and Letters*, by Don Joseph Rodriguez, the Chevalier Delambre, Baron de Zach, Dr. Thomas Thomson, Dr. Olinthus Gregory, and others; tending either to impugn or to defend the Trigonometrical Survey of England and Wales. 8vo. Price 3s.

8. THE ELEMENTS OF PLANE AND SPHERICAL TRIGONOMETRY. 12mo. Price 5s. bound.

9. A new and improved edition of Dr. *Hutton's* COURSE OF MATHEMATICS, Vols. I. and II. The 3d vol. is also in the Press, with additions and improvements.

10. MATHEMATICS FOR PRACTICAL MEN, being a Common Place-Book of Principles, Theorems, Rules, and Tables, in various departments of pure and mixed Mathematics, with their most useful applications; especially to the pursuits of Surveyors, Architects, Mechanics, and Civil Engineers. 8vo. with plates and many cuts. Price 14s.

LONDON:
PRINTED BY THOMAS DAVISON, WHITEFRIARS.

Librar

The
an
18th a
of sub
strateg
of wor
are m
journa
resear
spacio
readin

Corres

The
co
assist
examin
to the
Techn
been a

USI Jo

The
de
having
to all
feeling
person
establis
such a
length
course
work.

Centre

The
res
Centre
and Si
The C
compre
of nat
issues.

1. Al
Service
to appr
the ins
(a
(
(
(
or
(d
2. O
Membe
to time

For fur
Enclave

Date of Issue	Return.	Date of Issue	Return.